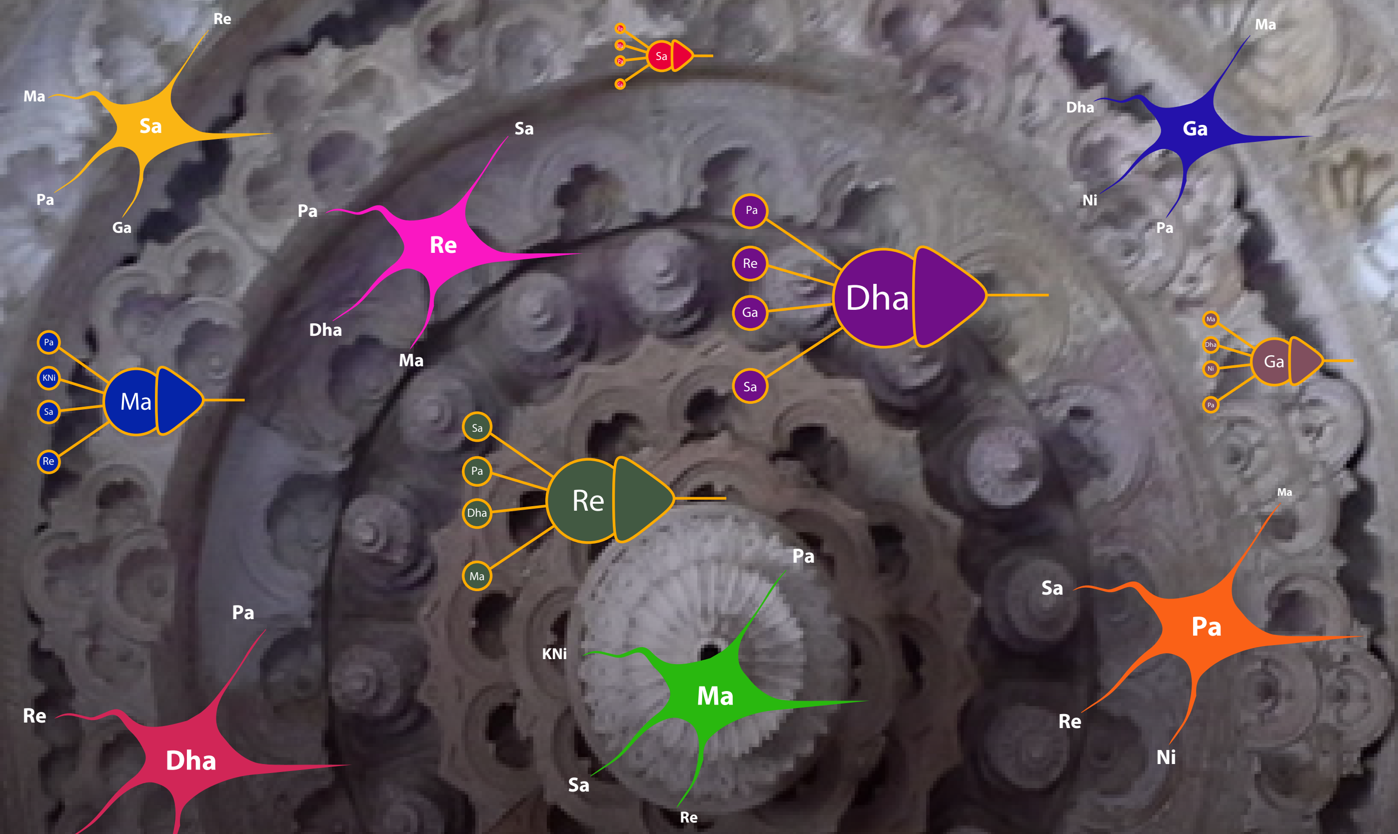

THE MUSIC OF MINDS AND MACHINES

A Deep Dive into the Generative Theory of Indian Music

Dr. Vinod Vidwans

FLAME UNIVERSITY

EVERLASTING experiences

THE MUSIC OF MINDS AND MACHINES

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This research is dedicated to …

Narada Muni, Bharata Muni, Matanga Muni and Sharangadeva

who laid down the foundations of Indian music,

Pandit Venkatamakhin

who envisaged the mathematical and computational approach to Indian music,

and Pandit Bhatkhande

who provided a grand systemic perspective of Indian music.

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Dr. Vinod Vidwans

Glossary of Terms

Aadhara Swara: Tonic note or a base note

Aantar-Marga: Meend or a glide. The term is also used to denote ascending and descending patterns of *swaras*.

Alpatva: Least used note

Amsha: Important note

Anu-Anuvadi: Sub-Asonant note

Anuvadi: Asonant note

Apanyasa: Short-resting note

Aroha: Ascending notes

Avaroha: Descending notes

Bahutva: Most used note

Bandish/ Gat: Musical composition

Graha: Starting note

Grama: Group of musical notes in a *Saptaka*

Jati System: System of classification of musical modes

Mandra: Lower note

Moorchchhana: Altered scale

Nyasa: Main resting note

Oudava: Taana with five notes

Raga: A musical melodic mode

Samvadi: Consonant or Sub-dominant note

Sanchari: Ascending and descending notes together

Saptaka: Musical scale

Shadava: Taana with six notes

Shruti: Microtone

Shuddha swara: Regular or pure form of the note

Sthayi: Stable *swaras*

Swara: Musical note

Taana: A string or a sequence of musical notes,

Taara: Higher note

Tala: Cycle of musical beats

Vadi: Dominant note or a Sonant

Varjya: Excluded note

Varna: Aesthetically arranged *swara* phrases

Vikruta swaras: Altered form of a note

Vivadi: Dissonant note

Notational Norms with examples

Norms for *Swara* Representations

The following table gives the correspondences between the Hindustani tone naming system, the western equivalent (following the Solfege Method) and their representation in this book.

***Swara* Name**	**Western Equivalent**	**Primary Symbol**	**Alternate representation**
Shadja	Do	Sa	sa
Komal Rishabha	Di/Ra	KRe	kRe, kre
Rishabha	Re	Re	re
Komal Gandhara	Ri/Me	KGa	kGa, kga
Gandhara	Mi	Ga	ga
Madhyama	Fa	Ma	ma
Teevra Madhyama	Fi/Se	MaT	Mat, mat
Panchama	Sol	Pa	pa
Komal Dhaivata	Si/Le	KDha	kDha, kdha
Dhaivata	La	Dha	dha
Komal Nishad	Li/Te	KNi	kNi, kni
Nishad	Ti	Ni	ni

There also exist note modifiers, used to denote octaves. Their use is demonstrated in the ensuing example.

Base Note:- ‘Sa’

Note that is an octave above the base:- ‘hSa’, ‘HSa’

Note that is an octave below the base:- ‘lSa’, ‘LSa’

Norms for Phrase Representations

Swara phrases are the sequences of *swaras* and therefore the order is important. Two-*swara* phrase is an ordered pair such as [sa, re] and three- *swara* phrase is [sa, re, ga] where the order of the *swaras* is very important. Therefore, every *swara* phrase is a k-tuple and it is represented in square brackets like [...] instead of (..). This is due to the computational convention.

An *Aroha* and *Avroha* are also a sequence of ascending and descending *swaras* respectively. *Aroha* is represented as A = [sa, re, ga, ma, pa, dha, ni, higher sa] for middle *Saptaka* and the *Avroha* is D= [higher sa, ni, dha, pa, ma, ga, re, sa] for the middle *Saptaka*.

As a convention, the middle octave representation also stands for the lower octave and higher octave representation unless specified. In specific cases, separate representations for the lower octave or the higher octave are specified by adding the lower octave markers or higher octave markers to the individual *swaras*. When more than one octave is involved, the octave markers are shown appropriately.

Formal Language Norms

A formal language for important concepts from Indian music is developed. Norms and conventions for the formal language are as follows.

The function FIRST-f stands for denoting the first member of a phrase. The function LAST-l stands for denoting the last member of a phrase. The function MEM-m stands for denoting a membership.

A set of phrases starting with *Graha swaras* is called a set START-G where G ∈ Graha a set of *Graha swaras* for a *Raga*.

For example, the set of *Graha swaras* can be Graha = {lni, ni, sa, kga, ga, pa}

The set START-G = {[ni, sa, re], [sa, re, ga], [kga, ma, pa], [pa, dha, ni]} you can see that all the strings are starting from *Graha swaras*.

A set of phrases ending with *Nyasa swaras* is called a set END-N where N ∈ Nyasa is a set of *Nyasa swaras* for a *Raga*.

For example, the set of *Nyasa swaras* can be Nyasa = {sa, ma, pa}

The set END-N = {[ni, sa], [sa, re, ma], [kga, ma, pa], [pa, dha, pa]} you can see that all the strings are ending with the *Nyasa swaras*.

A set of phrases having a particular *swara* as its member will be called a set MEM-M. For instance, if we want to show a set of phrases that have *Vadi swara* as a member of all the phrases then it can be represented as the set

MEMBER-Vadi where for a particular *Raga* if ga is the *Vadi* then this set will look like

MEMBER- ‘ga’ = {[sa, re, ga], [re, ga, re], [ga, ma, pa], [pa, ga, ma]}

Ordered pairs of *swaras* are denoted by ‘<’ and ‘>’. So, the ordered pair is made up of *swara* sa and *swara* pa is shown as <sa, pa>.

Standard set-theoretic and mathematical symbols are used wherever necessary.

From the Vice Chancellor's Desk

The mission of FLAME University includes providing a research-friendly ecosystem that fosters a robust research culture on campus. We encourage faculty and students to undertake original, theoretical, and applied research that is diverse, relevant and can impact the industry, policymaking, and society. Over the last couple of years, FLAME University has made considerable advancements in its research output. Many of the faculty members have been publishing in top-tier journals, which further strengthens our position as research focussed university. We are confident of further scaling up our research output and aspire to make FLAME a vibrant research hub. Publication of our faculty-authored books is a logical extension of our endeavours.

This book titled `The Music of Minds and Machines: A Deep Dive into the Generative Theory of Indian Music', authored by our senior faculty member, Dr. Vinod Vidwans demonstrates that the researchers at FLAME University have the requisite knowledge and are keenly interested in taking up research on Indic themes. This book tries to bring to light how the traditional Indic knowledge in the domain of music is relevant in the age of Artificial Intelligence (AI). Seemingly distant domains of music and computation have been synthesized in this work. There are several missing links and gaps while describing traditional Indian musicology and ancient scriptures. These have been identified and logically filled up by Dr. Vidwans, which requires rigour and depth of understanding of both domains. Robust principles of traditional Indian musicology are well articulated in computational terminology in this book. The author's keen interest, thorough analysis and mastery of both domains have made this synthesis possible and is proven with evidence by developing computational simulation systems. I am impressed by the efforts taken in designing, coding and conducting the simulations for Indian Ragas and Talas. The acumen of Dr Vidwans in both these domains is commendable. The research presented in this book is an example of multidisciplinary research and is perfectly in sync with the academic ethos at FLAME University. I hope it inspires researchers and academicians across disciplines.

My compliments to Dr. Vinod Vidwans for writing this book.

Dr. Dishan Kamdar

Vice Chancellor,

FLAME University, Pune, India

The Author Speaks

Indian music is practised, performed and understood in a variety of ways. India has two well-established streams of musical traditions, North Indian music and Carnatic music. There exists popular music and folk music as well. There are multiple styles of presentation of music from classical, and semiclassical to light classical. Thus, we see a plurality of musical practices and expressions. The Generative Theory of Indian Music (GTIM) contends that this plurality of musical practices is a surface-level phenomenon. Beneath this plurality and diversity of musical expressions lies a strong framework of musical logic. The GTIM argues that musical logic is generative by nature. From one base *swara* or a musical note, seven *swaras, as well as twenty-two (or even more) microtones (shrutis),* are generated by a consistent logical process. By application of the rules of musical logic to these *swaras,* and *shrutis*, musical phrases are generated. With certain other logical operations musically significant combinations of these phrases are generated that lead to the desired musical expression. Thus, from a single base *swara* the entire domain of music is generated. The whole process is generative. This is the central theme of GTIM. The GTIM is not merely a theoretical construct but has been implemented in AI systems and thoroughly tested through computer simulations.

In the Indian scholastic tradition, there is a concept called '*Prasthana Trayi'* or the 'Three Paths' to achieve the spiritual goals of life. *Brahmasutra*, *Upanishads* and *Bhagavad Gita* are considered as three important sources of knowledge for attaining the liberation or *Moksha*. Similarly, in the context of Indian music the literary trinity of the *Naradiya Shiksha,* the *Natyashastra* of Bharat Muni and the *Sangita Ratnakar* of Sharangadeva are the three core sources of the knowledge of Indian music and can be considered as the '*Prasthan Trayi'* of Indian music. The Generative Theory of Indian Music (GTIM) is firmly anchored in these three treatises. The GTIM attempts to connect the ancient wisdom of Indian music with contemporary advances in computing technology.

The GTIM brings to the fore, hitherto ignored aspects of Indian Music. It is almost inevitable for the amateur to get disoriented amongst this bombardment of points, counterpoints, theses and anti-theses. One may also come across concepts, perspectives and insights that are novel and unheard of. This is because the performative aspect of music is emphasised (not without cause) in the traditional system of education. The GTIM seeks to unearth the theoretical basis of music which is the foundation of all aspects of Indian Music, including the performative. Since this is an exposition of a logical theory, considerable care has been taken to avoid the usual 'smoke and mirrors' style shying away, that mars the discourse on Indian Music. It may be categorically stated that the ensuing discussions and demonstrations are entirely devoid of spectacle and miracle.

Musicians and professional practitioners of music will benefit tremendously from this theory. GTIM will give them a useful tool to introspect into their practices and repurpose their music. It is expected that this theory will be an intellectual delight for musicologists, music theoreticians, and music Gurus. This theory captures and articulates their subliminal feelings and deeper insights about their passion- Indian music. GTIM will provide them with scientific and logical answers to many of the unresolved questions and outstanding issues in music. This theory thus, will help music teachers in multiple ways. Musicians who are not familiar with computer technology need not go into the details of the computational algorithms that are discussed. As far as possible GTIM is presented in a non-technical language in this book. Logical and mathematical symbols are used whenever necessary.

Many Information Technology (IT) professionals and computer scientists are keenly interested in Indian music. Some of them have traditional training in Indian music as well. They want to understand the formal structure of Indian music. They are in search of a logical formalism of music as they want to co-relate music with mathematics. They are deeply interested in analysing Indian music. An appreciable number of researchers are working in the area of *Raga* recognition by machines. The GTIM will provide them with certain core concepts and formalisms to augment their research. Many of them are already engaged in research on computational Indian music. The GTIM will certainly provide them with the required theoretical foundations. Artificial Intelligence (AI) is evolving in multiple directions. Artificial Neural Nets (ANN), Machine Learning AI, Generative AI, and Robotics are some of the thrust areas of this development. GTIM will provide them with the required framework to take AI research in Indian music forward.

Any work of art consists of two components, form and content. The contention is that these two aspects are inseparable, inexplicably intertwined especially. The GTIM makes efforts to accommodate both the form and the content of musical composition in its theoretical framework. It makes the contention that the *Saptaka* or the octave significantly influences the structure and construction of musical phrases. The musical phrase can be treated as a generative unit which combines and recombines whilst following the constraints imposed by the 'Laws' of Music. As an ode to the seminal role of the *Saptaka*, the book itself is organised into seven parts. There are 22 chapters in the book, as a tribute to the *shrutis* or the microtones that form the crux of the GTIM. The form and structure of the book, even though dictated by metaphor, do not affect the continuity of the chapters. The 22 chapters string together seamlessly irrespective of these divisions.

The first part is dedicated to the aesthetic and philosophical foundations of GTIM. It talks about how the philosophy of *Advaita Vedanta* provides robust foundations for the generative theory of Indian music. The discussion looks for a metaphorical similarity between the Vedantic view of the process of the world coming into existence and compares it with the process of a single base *swara* manifesting into a multifaceted musical reality. This metaphor has an evolutionary and computational dimension. This transformational journey of a *swara* confronts three realities-namely, a mathematical reality, a computational reality and the musical reality. A brief historical overview suggests that the evolution and development of Indian music was an organic process. We can see certain evolutionary patterns in this growth that resulted in the doctrine of *Raga*. The concept of *Raga* as a musical design of *swaras* is quite note-worthy. From antiquity to medieval and modern times, *Ragas* are considered the core of Indian musical expressions. The journey towards the present begins with '*Jati*' music, '*Grama Ragas*', and *Raga-Ragini* systems, and culminates into the *Mela* system and later on in the *Thaata* system. Indian music has a formidable doctrine of the *Raga* music but more interestingly it is deeply anchored in the Indian philosophical ethos. Thus, the first part of the book takes a deep dive into the aesthetic and philosophical foundations of Indian music.

This book provides a broader perspective of the generative theory of Indian music. The overall approach is not to commit to any particular style, genre, paradigm or musical school or *Gharana.* An attempt is made to represent musical concepts and practices in a rigorous way to have a concrete understanding of Indian music. As a result, abstract logical formulations are extracted from the musical practices of the past and the present music. The second part of this book achieves this through a rigorous discussion on *swaras, shrutis*, *Saptakas* and contemporary practised musical scales. A chapter is dedicated to understanding the role of consonances and harmonics in Indian music. Another chapter is dedicated to *Tanapura* harmonics as well. The discussion enters into the domains of acoustics, physics and the logical foundations for Indian music.

It is claimed that Indian music is highly scientific and logical. The third part of this book focuses on this aspect. A chapter is dedicated to providing a logical framework for such a discourse. At an abstract level, it is possible to envisage Indian music as a logico-mathematical paradigm and a rigorous logical system can be developed. This chapter develops an axiomatic system suitable for Indian music based on the principles mentioned in the *Natyashastra*. The following chapter deals with the laws of musical intelligence consistent with the axiomatic system. Laws of musical intelligence are extracted from the *Natyashastra,* ancient musical practices, principles of consonances, contemporary musical practices and the computational simulations of the same. The author has designed and developed an Artificially Intelligent expert system, called *AIRaga* to conduct the simulation studies and arrived at results that support these contentions.

The fourth part of this book is dedicated to an analysis of the concept of *Raga*. This part emphasizes the issues of characterizations of the *Raga*, the formal definition of the *Raga*, the *Raga* generation process and finally the development of the *Raga* classification system called the '*Nava Gana'* system. *Ganas* are very similar to *Melas* of Carnatic music or the *Thaata* of the North Indian music but the philosophy and logic of the *Nava Gana* system is entirely different. Taking *Vadi-Samvadi swaras* of a *Raga* as the classification criteria, a scheme of classification of *Ragas* is developed. The GTIM recognizes nine such *Ganas* and all the *Ragas* are classified within this system. The classification system is developed most comprehensively so that it can classify all the existing *Ragas* as well as all the possible *Ragas*. Since it is a computational classification system most of the loopholes of the other classification systems are avoided.

The *Nava Gana* classification system provides computationally significant dynamics of the *Raga* generation process. It demonstrates how the *Moorchchhanas* of modern *swara Saptaka* lead to the generation of seed *Ragas* by application of combinatorial logic and then how the seed *Ragas* get transformed into the real *Ragas* by applications of musical logic. This is possible due to the formal characterization of *Raga*. A chapter is dedicated to explaining the formalization of *Raga*. This is a very important and seminal chapter in GTIM because no other theoretical work has tried to characterize and formalize the concept of *Raga*.

The fifth part of this book begins with the description of transforming the seed *Ragas* into the real *Ragas*. The computational algorithm based on the principles of musical logic developed in earlier chapters is instrumental in this transformation. A separate chapter describes the step-by-step process of *Raga* formation. A variety of *Ragas* such as simple *Ragas*, augmented *Ragas* having dual forms of *swaras*, *Ragas* with *Varjya swaras*, *Ragas* with different *Varjya swaras* in *Aroha* and *Avroha* as well as *Tri-Gandhar Ragas* are generated. Many non-conventional *Ragas* are also generated. The *Raga* generation process is highly complex that involves evolutionary computational dynamics.

The *Ganas* are the broad nine classes, as mentioned earlier, where all the generated *Ragas* find their place. There can be multiple *Ragas* within each *Gana*. Therefore, it is required to make sub-classes or categories of *Ragas* to make the system elegant. Based on the simple logic of the number of *swaras* in the *Aroha* and/ or *Avroha,* a scheme of categorization or '*Vargas*' is developed. The tradition already follows this logic of categorization of *Ragas*. The GTIM implements this scheme of categorization under the *Gana* system. Thus, there are *Ganas* and within the *Ganas,* there are categories or the *Vargas* of *Ragas* such as *Sampurna, Shadava, Oudava* etc.

The sixth part of the book focuses on theoretical aspects of the generation of musical composition called '*Bandish*'. *Bandish* is a well-organized musical expression articulating the aesthetic emotion. The aesthetic emotion could be based on the lyrics where appropriate *Raga* is chosen as a vehicle to enhance the emotion. The second type of *Bandish* articulates the aesthetic emotion inherent in *Raga* itself without using lyrics. Mostly such a *Bandish* is called a *Gat* and presented using musical instruments. GTIM provides the theoretical framework for the second type of *Bandish/ Gat* generation. The discussion on the computational generation of lyrics is beyond the scope of this book because that itself is a separate domain of research.

A *Bandish* is the soul of a *Raga* because the aesthetic impact of a *Raga* gradually unfolds through it. A chapter is dedicated to describing the structure of a *Bandish*. The discussion about the structure of a *Gat/ Bandish* is very important from the computational point of view. There exists an intricate and inherent correlation between the structure of a *Gat/ Bandish* and the *swaras* used in the *Raga*. Four important *swaras* define a *Raga*. They are the *Vadi, Samvadi, Anuvadi* and *Anu-Anuvadi swaras*. Especially, the phrases in a *Bandish/ Gat* are made up of these four types of *swaras* to manifest the aesthetic emotion of a *Raga.* There is a separate chapter on phrase generation and its computational mechanism suitable for the generation of a *Bandish/ Gat*. The chapter elaborates on the mechanisms of generating various types of phrases using the above-mentioned important *swaras* in the *Raga*. There are sequential phrases, non-sequential phrases, ornamental phrases, glide phrases called *Meend* phrases, single-*swara* phrases as well as long phrases up to eight *swaras*. Even the longer phrases are generated by joining small phrases. Along with generative mechanisms, the formal logic of phrase generation is elaborately articulated in this chapter.

The last chapter in the sixth part is dedicated to developing a theoretical structure for the elaboration of a *Raga* called *Raga-Vistara* and that is articulated formally. There exists a huge diversity of presentation styles of *Raga-Vistara* in Indian music. The diversity of presentation styles exists in terms of genre, *Gharanas*, individual styles (*Manodharma*), percussion instruments, North Indian and Carnatic styles of music, and the multitude of contemporary practices. The GTIM does not focus on any particular way of performance. The main objective of this discussion on *Raga-Vistara* of a *Bandish* is delimited to the theory construction, understanding the generic structure of *Raga-Vistara* and the formal representation.

The last and seventh part of the book is dedicated to the theory building for Indian rhythms or *Talas*. India has a long tradition of *Tala* music but contemporary music in North India as well as Carnatic music have developed their systems of *Talas*. North Indian music has *Talas* such as *Tritala, Eka Tala, Jhapa Tala, and Roopaka Tala* while Carnatic music has developed the scheme of *Suladi Sapta Talas*. Along with *Suladi Sapta Talas,* there are popular *Talas* called *Chapu Talas*. These *Talas* are relatively new as compared to the ancient practices articulated in treatises such as *Sangit Ratnakara*. Currently, there is no unifying system in place that can cover all the contemporary *Tala* practices in North Indian music or Carnatic music. Two chapters on *Talas* provide the generative computational paradigm of nine classes of *Talas* called '*Nava Gana Talas*' that can accommodate all the existing *Talas*: contemporary North Indian and Carnatic *Talas* as well as the ancient *Talas*.

The *Nava Gana Tala* system is inspired by the concepts and principles of *Dasha Pranas* mentioned in the tradition. So, this system is consistent with the ancient system and provides the scope for reinterpreting ancient and contemporary *Talas*. This system is named the *Nava Gana Tala* System of Indian *Talas*. The new scheme is developed and tested using Artificial Intelligence (AI) system called *AI-Tala* and can generate new *Talas* as well as play and render them. The *Sanskrit* term for a computer is `*Samganaka*’. ‘*Gananam*’ means computing in *Sanskrit*. The new scheme of *Talas* is tested by *AI-Tala* and a lot of computing efforts have gone into developing this system therefore the term ‘*Gana*’ seems appropriate.

To reflect upon the overall contribution of the book, it may be said that the GTIM provides a formal and mathematical representation of most of the foundational notions of Indian music such as *Swara, Shruti, Saptaka, Raga, Tala, Bandish* and many others. Formal representations are necessary to bring clarity to musical concepts which are otherwise considered abstract. Traditional musicians and performers very rarely attempt to define these concepts in a very precise way. The book certainly fills this lacuna.

Apart from formally defining the established theoretical concepts of Indian music, the GTIM has introduced and rigorously articulated many new concepts. These concepts include, ‘*Nitya swaras*’, ‘Hierarchy of Harmonic Strength of *Swaras* and *Shrutis*’, ‘Law of Co-existence of *Swaras*’, ‘Law of Emotive *Swaras*’ and many others. These are completely new concepts and are not found in the existing literature on Indian music. The author of this book has worked on these concepts rigorously, tested them, validated them through computer simulations and considers these concepts as paradigms in themselves. Without these concepts, the generative theory of Indian music is not possible.

Dr. Vinod Vidwans

The Music of Minds and Machines

A Deep Dive into the Generative Theory of Indian Music

Contents

PART V

The Birth of *Ragas* (Pa)

PART VI

The Craft of Composing (Dha)

PART VII

Pulsating Percussions (Ni)

PART VIII

Bhairavi (Higher Sa)

PART IX

Appendices

PART I

Tuning the Strings (Sa)

CHAPTER 1

Aesthetic and Philosophical Foundations of Indian Music

Introduction

Music is studied from various perspectives. The musicologist or a researcher always has certain objectives for such a study. To fulfil those objectives a researcher gathers resources and conducts the enquiry. From ancient times music is considered an art in the West as well as in India. Therefore, music has been studied the world over using art-specific methods and standards. However, recently due to the developments in Information Technology (IT), new methods have been explored. The Generative Theory of Indian Music (GTIM) certainly belongs to the contemporary approach. However, core knowledge of any discipline is never bound by methodological constraints. Core knowledge is always independent of methodologies. In the case of the artistic domain mostly the methods of philosophical analysis and conceptual analysis are prevalent. There exists a good amount of literature that throws light on fundamental concepts and principles of art as well as the processes of artistic creations and art appreciation. Broadly it is termed as a theory of art and aesthetics. It attempts to study concepts and principles of art creation and appreciation applicable across various forms of art such as painting, sculpture, music, dance, theatre etc. For example, *Natyashastra* of Bharata deals with various theoretical issues about the art of theatre in general and also deals with relevant topics from related art forms such as music and dance. To make the matter simple it can be said that there exist generic theories and there are domain-specific theories of art and aesthetics.

From a broader perspective, it can be said that there are three types of theories of art and aesthetics. Most of the theories focus on the nature of aesthetic experience. They try to critically analyse the audience's response to any work of art. It may be a theatrical performance or a musical composition or a painting. It is a meta-level perspective to understand and classify various facets of the artistic experience. The domain of art and aesthetics is dominated by such theories.

There are very few theories which belong to the second category that attempts to understand the structure of a 'work of art'. They try to analyse the elements and principles of beauty embedded in the work of art. The third type of theory tries to look at the artistic phenomenon from an artist's point of view or a creator's point of view. They are more concerned about the nature of the creative process and how a work of art comes into existence. The present Generative Theory of Indian Music (GTIM) belongs to this third category.

Generative Perspective

The present theory attempts to understand the phenomenon of Indian music from the generative perspective. At the outset itself, it should be clarified that GTIM does not probe into a musician's psychological creative process. It tries to probe into the phenomenon of the generation of a musical composition. It tries to understand the `artist-neutral' process of music generation. It is also called a process of Music making. It tries to build a computational model of the generative process of music. It follows a strict scientific methodology of simulation to achieve this.

The theory postulates that the objective/ computational model of the music generation process will lead to a better scientific understanding of Indian music. It envisages a generative model of Indian music. It postulates that from one *swara* (a sound frequency) twenty-two *shrutis* (microtones) can be generated by following rules of musical logic. From these twenty-two *shrutis*, sets of seven or twelve *swaras* can be selected. Then these *swaras* can be organized in ascending and descending order to bring in the hierarchical order. This higher order will lead to the emergence of well-defined `*Moorchchhanas*' (classes or altered scales) and then `*Ragas*'. From the set of *swaras/ shrutis*, small groups of two, three or four *swaras* can be generated by following certain rules of music. Taking this approach forward many such groups of *swaras* can be generated called musical phrases and some of the phrases can be aesthetically and musically pleasing. Certain most pleasing phrases can be shortlisted as catch-phrases (traditionally called `*Chalan*' or `*Pakad*'). Such phrases can be organized eventually to generate a well-formed musical `*Bandish*' or a composition. All this will happen by following certain musical logic and rules. Eventually, these compositions will have inherent aesthetic power to appeal to the audience. The stylized expressions with emergent aesthetic music will be the logical conclusion of the whole generative process. Thus, this theory attempts to develop a rigorous aural logical generative system for Indian music capable of generating fathomless and boundary-less infinite music. This theory attempts to demonstrate and analyse how just a single *swara* can lead to the ocean of music. In a sense, this theory captures the whole thematic and historical development of Indian music without referring to the history. The theory represents the living and thriving tradition of Indian music. The core theme of the theory is that a single *swara* generates infinite music. That is the reason this theory is called a `Generative Theory of Indian Music'.

Philosophical Anchoring

From a philosophical point of view, this theory goes closer to the traditional philosophy of `*Advaita Vedanta*' (non-dualistic Vedic philosophy). As per this philosophy, we see the pluralistic multifaceted world originating from a single principle or entity called '*Brahman*'. In the context of music, it can be said that the infinite musical expression of music that we experience and rejoice in is a surface phenomenon. At the roots of these expressions lies the one single core principle called `*Nada Brahman*'. From this unified singularity of `*Nada Brahman'* a musically beautiful world of expressions is generated. The whole generative process is highly logical and mathematical. From a philosophical point of view, this is the core contribution of GTIM.

असद्वा इदमग्र आसीत्। ततो वै सदजायत। तदात्मानँ् स्वयमकुरुत। तस्मात्तत्सुकृतमुच्यत इति। यद्वैतत्सुकृतम्। रसो वै सः।

[Jog, D, V. (Ed), 2018, pp. 221-222].

This may be translated as 'Non-Existence' or 'That' existed then. There emerged 'Existence'. 'That' created itself, and therefore, it was *'Sukruta'* – the 'Well-Made'. The *'Sukruta'* is *'Rasa'.* These profound words from *Taittiriya* Upanishad provide philosophical context to all the later discussions on aesthetics in India. The term '*Rasa*', which is understood as aesthetic emotion/ experience in the domains of poetics, literature and theatre has a legacy in these Upanishadic *shlokas*. It says that there existed an 'indescribable' entity or an entity that is 'beyond qualities and so cannot be described by words '(*Gunaateeta Brahman*). It created/ transformed itself in a form that has qualities (*Saguna Brahman*) and that is describable in words. Since the *Brahman* has created itself (*Swayam krutah*) the *Saguna Brahman* is called '*Sukruta*', - 'the Good Deed' or the 'Holy Act'.

In the domain of artistic creation, this cosmic/ metaphysical phenomenon is interpreted and metaphorically associated with the creative activities of an artist.

Thus, it is assumed that an artistic ‘Creation’ is the ‘Creator’ itself. A creator transforms his or her ‘being’ into a ‘creation’ or a work of art. The world perceives it as the artist’s expression- Art as ‘Self-Expression’. In this sense human creation is analogous to cosmic creation and the phenomenon of cosmic creation may be correlated to human creation.

Taking the analogy forward various aspects of cosmic creation can be related to human creation. The above-mentioned Upanishadic *shloka* says that the cosmic creation is called ‘*Sukruta*’, and it is nothing but ‘*Rasa*’ itself. The ‘*Rasa*’ leads to ‘*Ananda*’, the ‘Cosmic Bliss’. Similarly, human creation leads to aesthetic bliss or aesthetic experience. The above-mentioned Upanishadic thought is further elaborated in Vedanta philosophy. From the philosophical point of view of Vedanta, aesthetic activity and aesthetic experience are understood as described by a noted Indian philosopher Hiriyanna as follows. In *Vedanta*, *Brahman* – the Ultimate Truth – represents the ‘Inner Harmony’ of the Universe. The realization of *Brahman* is the realization of Universal Harmony. A metaphysical goal of every artist is to attain this state which is direct and not mediated. As per *Vedanta*, art aims to create an ideal work of art by inducing an attitude of complete detachment and trying to be as close as possible to the state of *Brahman*. Therefore, the work of art should lead the artist as well as the audience to that restful bliss, a realization of that harmony. Universal harmony is realized in one’s own experience and not merely intellectually apprehended (Hiriyanna 1954: 6–10).

Thus, the ultimate objective of artistic expression is to evoke a unique kind of aesthetic experience- to take the audience into the realm of non-worldly, virtual experience. Artistic creation, therefore, is a complete world in itself. To achieve this, the artist constructs an imaginative world that is complete by itself. A painting, a sculpture, a music performance or a theatrical performance is a complete world by itself. A performing artist creates an imaginative world using the artistic devices of language, poetic phrases, dialogues, rhyming words, beautiful hand gestures, and body postures. In painting, sculpture, and architecture, artists use the visual language of shapes, forms, colours, texture, and positive and negative spaces to create a reality that is complete in itself. This artistic world has its logic, its purpose and its own personality. The creators’ thoughts and actions are reflected and manifested in this reality. The creator has total command over this world. Anandvardhana in his treatise called ‘*Dhwanyaloka*’ while elaborating on one of his *‘karikas’* articulates this thought as follows.

अपारे काव्यसंसारे कविरेक: प्रजापतिः। यथास्मै रोचते विश्वं तथा वै परिवर्तते ॥ [Nagendra, 1962, p. 312].

"In the boundless world of poetry, a poet is the Prajapati (Brahma- the 'Creator'). He changes the universe as and when he thinks the best." Thus, the creator is the master of his creations or his artistic world. Therefore, an artist's ability to visualize such a reality and his/her skill to manifest it authentically plays a vital role in this process. The process has a structure, logic and language of its own. There exists a language of creative expression and it requires a grammar of aesthetics. This grammar is implicitly present and is followed by artists intuitively. Artists also have their own explicit grammar or canons for the language of artistic articulation. Traditional treatises on art such as *Natyashastra* or *Shilpashastra* give elaborate descriptions of the respective domain-specific grammars of artistic manifestations and the rules, canons and artistic conventions.

Art as Computation

Art is an act of creating, expressing, and making. Art is a presentation and representation of ideas, thoughts, feelings, and experiences. The word for art in Indian tradition is कला. It is etymologically derived from the root '*kal*' which means counting, calculating, or computation. It also means to do, to make, to accomplish, to observe, to perceive, to recognize, or to take notice [Apte, V. S., 1970]. The word 'कल्' thus covers a large set of activities. Artistic activity involves creative perception and calculation for visualization and articulation respectively. This etymological meaning of the word 'कल्' i.e., to calculate or measure led to further exposition and development of quantitative standards for artistic practices in India.

In the field of visual and performing arts, the calculative and computational aspects of art have received an elaborate exposition. Indian arts, known for their spiritual and metaphysical content are very much quantitative in their physical manifestations. This is aimed at achieving the aforementioned 'Universal Harmony'. It is fascinating to see that all the theoretical concepts of Indian arts have either quantitative or computational aspects. Many of us are familiar with the idea of *Tala-Mana Pramana* ratios used in *Shilpashastra* [Trivedi, K, 2003-04, pp. 497-500]. Similarly, all the Indian art forms have their own domain-specific measurement systems and computational grammar. It is beyond the scope of this chapter to give an elaborate exposition of all the concepts from all the domains from a computational point of view.

Artistic creations have profound computational foundations in Indian arts. The computational foundations enhance the quality of aesthetic experience. They also facilitate the process of attaining the 'Universal Harmony'. There exists a correlation between artistic computation and the aesthetic experience. It is fascinating to see that underneath the evocative ability of Indian music, there are quantitative and computational principles or a 'Computational Grammar of Music' that makes this aesthetic experience possible. It is interesting to see how these rules that are computational in nature play an active role and contribute to the generation of music that leads to an aesthetic experience. Bharata Muni's *Natyashastra*, Narada Muni's *Naradiya Shiksha* and Sharangadeva's *Sangita Ratnakar* are well-known foundational treatises on Indian music. The principles and rules of the grammar of Indian music are well-articulated in these treatises. All the discussion in this book is based on these treatises. To understand these rules authentically, the author has designed and made a special musical instrument called '*Bharat Veena*'. All the concepts from these treatises can be tested and validated on this *Veena*. *Bharat Veena* is designed and developed based on the description from Bharata's *Natyashastra*.

Throughout this book, the readers will understand that the rules of the grammar of Indian music have computational qualities and how their manifestation leads to the generation of musical concepts. It also explains how musical compositions lead to aesthetic experience. An important aspect of this discussion is that there exists an inherent generative logic foundational to these rules. A unique characteristic of generative grammar is that from one base concept of *Shadja swara,* by applying a few basic rules, all the other musical concepts can be generated. This is precisely the reason it is termed as a 'generative grammar'. While discussing the nature of '*Brahman*' and the evolution of this world, the Upanishads have mentioned similar thoughts. There exists an inherent generative logic in the process of how the singular '*Brahman*' transformed itself into the plural world. Especially, the *Taittiriya* and *Chhandogya* Upanishads have very convincingly described this process. They say, initially, the '*Brahman*' was one. It decided to become many.

सोऽकामयत बहु स्यां प्रजायेयेति | [Jog, D, V. (Ed), 2018, p. 218],

That *Brahman* desired that it will transform into many. This statement is from the *Taittiriya* Upanishad while the next statement is from the *Chhandogya* Upanishad.

तदैक्षत बहु स्यां प्रजायेयेति | [Jog, D, V. (Ed), 2018, p. 420],

That *Brahman* envisioned or envisaged that it will transform into many.

In the spirit of the above statements from Upanishads, by extending this metaphor, it is shown, in the context of Indian music, that the single base note called *Shadja swara* or the '*Aadhar' swara*, generates the rest of the other *swaras* of a *Saptaka* (an octave) and then within a *Saptaka* various musically significant relationships among *swaras* are established. All this is achieved by following certain musical rules inherently present. Eventually, all these relationships contribute to the generation of music. From just one single *Shadja swara* the whole world of music, with all its multiplicities can be created. This phenomenon is demonstrated in this book in a step-by-step manner. Consequently, computable relationships between and among *swaras* lead to the generation of *Jatis* (classes), *Moorchchhanas* (ordered sequence of swaras), *Taanas* (elaborations of musicale phrases) and eventually- *Ragas* (Indian melodic modes). This underlying computational generative process results in beautiful music that has aesthetic qualities.

Any scientific theory is a comprehensive well-knit system of core concepts and core principles and is not just a collection of rules. A well-formed system has well-defined relations between all the core concepts, well-defined relations between all the core principles and well-defined relations between all the core concepts and all the core principles. The present theory of Computational Indian Music (GTIM) takes care of all such relations in a rigorous way. For example, *Shadja-Panchama Bhava* and *Shadja-Madhyama Bhava* mentioned in the *Natyashastra* are core two independent musical principles in this theory. They are related to each other. From a mathematical perspective, they are the opposite of each other. The *Shadja-Panchama Bhava* is based on the mathematical principle of 'Arithmetic Mean' while the *Shadja-Madhyama Bhava* is based on the mathematical principle of 'Harmonic Mean'. Arithmetic Mean and Harmonic Mean are opposite of each other. The system has appropriate places and roles for both these principles. In this theory, these principles are the core principle and many other musical concepts are directly or indirectly derived from them. For instance, the concepts of *Vadi swara* and *Samvadi swara* in a *Raga* are based on the above principles. In any *Raga,* if the *Vadi swara* is *Rishabha* then the *Samvadi swara* in that *Raga* would be *Dhaivata swara*. This is done by application of *Shadja-Panchama Bhava*. Similarly, if in a *Raga, Dhaivata* happens to be a *Vadi swara* then *Rishabha* can be a *Samvadi swara* due to *Shadja-Madhyama Bhava*. This is a simple example and easy to understand however, many other rules and their inter-relations are highly complex. This theory accommodates all such simple and complex rules, concepts and their relations in a consistent manner. Apart from *Vadi* and *Samvadi swaras,* there are many other important *swaras* in the *Raga*. Their definitions, roles, and relations with other *swaras* are highly complex. GTIM defines and explains all the traditional concepts and principles of music. At times traditional concepts are redefined in a more theoretical way. Many of the rules are rigorously scrutinized and modified and many rules are newly added to the theory. As already mentioned, traditional resources on music are not rigorous and theoretically precise. So, while developing this theory many concepts and rules have been redefined and reworked. Many new concepts and rules have been developed and added to the theory. This theory attempts to organize all the concepts and principles of Indian music in a highly rigorous, logically precise and consistent and unified way. This is the real strength of the Generative Theory of Indian Music (GTIM). However, it must be noted that an attempt has been made to keep theory as less technical as possible without sacrificing rigour. It is always possible to develop a theory that is tightly formalized but beyond a point, it becomes incomprehensible to the majority of the readers. A handful of readers can understand such a formalism. Here a balanced approach is adopted to develop the formalism that is required to articulate the concepts and principles of Indian music in a simple but rigorous way. Wherever necessary, a musical explanation of each formalism is provided so that readers who are not technology-oriented will be able to grasp the crux of the theory.

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CHAPTER 2

The Three Realities

Introduction

Contemporary Indian music is waiting for a major transformation. Despite a very strong Western influence, traditional music is holding on to its trenches. There exists a tremendous impact of traditional Indian music on the common audience. This means that there is a certain inherent strength in Indian music and due to this, it has withstood the proving grounds of time. Throughout the ages, Indian music has gone through many transitions. In response to these changes and challenges, many new genres came into existence. *Dhrupad, Khyal, Dhamar, Thumari, Bhajan, Tappa, Kavvali*, light music etc. were the collective responses to these transitions. These musical expressions enriched the tradition further. Indian music has succeeded in preserving and protecting the core of Indian music. *Raga* and *Tala* are the most valuable gifts to world music by Indian tradition. The 'Generative Theory of Indian Music' (GTIM) thoroughly and rigorously defines and discusses all such concepts.

The word 'Generative' is highly meaningful and functional in GTIM. Music is practised and performed in a variety of ways. We have both the Hindustani and the Carnatic systems which function like the Ganga and Yamuna, the holy rivers, of our musical civilisation. There exists popular music and folk music also. There are multiple styles of presentation of music such as *Dhrupad, Khayal, Thumri* etc. We see a plurality of musical expressions. The GTIM theory advocates that this plurality is apparent. GTIM stresses that underneath this plurality lies a robust framework of musical logic. This musical logic is generative by nature. This is the central thesis of GTIM.

Indian Music: Three Realities

The generative theory of Indian music (GTIM) is strongly anchored in three realities. To understand the generative theory of Indian music it is necessary to have proper insights into these three `Realities'. These three realities may be defined as: a 'Mathematical Reality', a 'Computational Reality' and the 'Musical Reality'. It will be interesting to see how these three realities provided a broad foundation and impacted the evolution of this theory. The theory of generative music is strongly based on a special kind of mathematical logic. It is more appropriate to say that a special kind of mathematical logic is the `deep-structure' foundation of this theory. This is the first `Mathematical Reality'.

All scientific theories in natural sciences or social science are based on logic. Inductive and deductive logics are the most prevalent modes of logical and scientific enquiry. There are many varieties and applications of these methods. Every discipline of knowledge has its own logic and related method of conducting research. In music in general and Indian music in particular, there is no such well-established logical or scientific research methodology to arrive at a theory of Indian music. Therefore, the first and most important challenge has been the challenge of developing appropriate logic for Indian music and the resultant methodology. GTIM has achieved to develop such logic and allied computational methods. This logic is based on the traditional principles of Indian music called *`Shadja- Panchama Bhava'* and the *`Shadja-Madhyama Bhava'*. The tradition never had intentions to realize the mathematical importance and significance of these principles though. There are many logical and mathematical principles in Indian music but they are understood as musical principles and their mathematical analysis and applications are very rarely articulated. Many such principles and concepts are explored in GTIM. Apart from that many new concepts and principles are derived, proved, formalized and established. The concepts and principles from the writings of Narada Muni, Bharata Muni and Sharangadeva are the main sources of inspiration to develop this generative theory of Indian music. Some of the concepts and principles are further developed and formalized rigorously in this theory. There are a few concepts and principles that are newly developed to consolidate the theory. Thus, by riding on the robust ancient musical traditions, the present generative theory of Indian music (GTIM) insinuates a new direction of musical paradigm.

In the generative theory of Indian music (GTIM), a system of mathematical concepts and theorems is developed that is suitable to music in general but the focus is Indian music. Every attempt is made to develop a robust logic for the system. This may be termed `Musical Logic' or the `Aural Logic' for Indian music. Care is taken that this logic will do justice to the musical sensibilities and resultant aesthetic experience. This is the nature of the `Mathematical Reality' underlying Indian music. For the validation of this theory, the computational approach came as a blessing in disguise. Computational simulation research is well-established now and therefore it was decided that this approach would be beneficial for developing and validating the theory. The literature survey and the author's explorations suggest that the conventional methods of research in

Indian music didn't yield any promising results so far. Available data sets on Indian music such as musical notations are not explicit enough to relate to the theoretical musical concepts articulated. The audio data is quite dense and the available technology to the date is not sufficiently equipped to extract *swaras* (musical notes) and *shrutis* (microtones) from the audio data that is needed for musical analysis. Looking at the nature of Indian music and performance practices it was realized that the existing methods of scientific research and other available scientific resources are not adequate as of now. Therefore, simulation research was considered the most apt approach available. This is the second, Computational reality.

Music is an art and `*Shastra*' but there is a science of music as well. The generative theory of Indian music tries to establish the same. From the audience and connoisseurs' point of view, Indian music is considered a great `Art Tradition' and is highly revered. Music is not only a unique symbol of Indian artistic tradition but it is the crux of Indian tradition. The Indian audience is highly committed to maintaining, preserving and taking Indian music forward and passing it on to the next generation. Many renowned singers and performers, their personalities and charisma, the divine music, the divine musical experience and the divine memories, all this put together constitute the collective `Musical Reality'. This is the third reality.

Indian music is highly complex and multi-dimensional. A survey of the literature and repertoire suggests that musicologists have tried to understand and theorize Indian music from various approaches based on the prevalent norms and context. Historical studies and textual analysis appeared to be popular methodologies in music research. During ancient times *Naradiya Shiksha*, Bharata's *Natyashastra*, and *Sangita Ratnakara* of Sharangadeva had laid down the theoretical foundations of Indian music. In medieval and modern times Pandit Venkatamakhin and Pandit Bhatkhande had tried to theorize music in their ways appropriate to explain prevalent musical practices. Ancient treatises tried to define basic concepts of music. Modern musicologists tried to develop classification systems for *Ragas*. Thus, music is studied and understood in various ways. Recently, many computational paradigms are being explored to understand various facets of Indian music.

The `Generative Theory of Indian Music' (GTIM), is not limited to the music generated on the computer or the music generated by the computer. It is a generic theory of Indian music. It applies to all kinds of music in general and to Indian music in particular. At the core, it is a theory of Music. Computers and computations are used in various possible ways to develop, manifest and validate this theory. From a theoretical point of view, a system of computational algorithms suitable for Indian music has been developed and this is the major contribution (or even a vindication) of this theory. Computers are used to test and verify these algorithms through simulations.

Throughout the development of this theory, a simulation method is used to verify the algorithms. Simulation research is now well-established in the field of science and social sciences and is considered a valid method of research. Since the topic of generating creative musical composition demanded the involvement of computers and the latest technology, it was decided that for the research on computational Indian music, the method of simulation would be most appropriate. In the simulation method, you generate the phenomenon in question on the computer and then conduct the analysis.

As we know for verifying a scientific concept, we conduct experiments in the laboratory. For example, to understand the dispersion of light through prism we try to recreate the phenomenon of dispersion in the laboratory and then take observations and analyse them. Similarly, to develop this theory computers are used as a laboratory tool. For instance, take the phenomenon of creating a musical composition. In this case, based on the aural logic for Indian music, a computational algorithm is developed and a musical composition or `*Bandish*' is composed, by a computer and rendered. Then the computer also generates a text file of the composition with a detailed description of various musical parameters. We can listen to the computer-generated composition and correlate the description from the text file and analyse it and arrive at conclusions. We can preserve this text file for future reference. So, in this case, the computer has become a laboratory. The computer has become a singing lab. Multiple Gigabytes of data are generated, tested, rejected, selected and validated in this process. Every computer-generated composition has gone through this process. Every computational algorithm has gone through this process. The author has developed Artificial Intelligence (AI) systems called *AIRaga* and *AITala* for testing and validation of the theory. Therefore, the computer generates musical composition by itself without any human intervention or support. Then the results are tested thoroughly. This attempt of using AI for music has been successful beyond expectations.

The philosophy behind this attempt is that the `Aural Logical System', should be complete in itself. After codification of all the concepts, principles and theorems of the `Aural Logic' in a computer program, if this logic is `true' and `valid' then the system should be capable of generating `musically' acceptable compositions. The computer-generated compositions should match with the compositions created by musicians or at least they should be reasonably close to human creations and have acceptable musical qualities. Also, every time the computer should generate a `new' composition without repeating the previous ones. The present system has succeeded in achieving this beyond expectations. This system is already presented in many seminars and shown to many knowledgeable musicians in this regard and got their approval. In the process, they also made many useful suggestions which are then implemented for further improvements. All these suggestions helped in making the theory more robust.

Computers have their machine-specific strengths. Computers can produce a variety of sounds, real as well as artificial. We can design and develop digital instruments which do not exist in reality. For example, we can create an instrument that has a combination of sounds similar to *Shahanai* and violin. The author has designed and developed new digital instruments in this regard. We can play around with various sound effects that are specific to such digital instruments. Computers open up such possibilities for artificial creativity. Another example could be the voice range. The human voice can move freely in three octaves and some musicians can go a half octave beyond that. On some musical instruments, we can play up to four octaves. But in the case of computers, there is no limit. Probably listening capability of humans is the limit. We can generate sound on computers that can move in seven octaves or nine octaves. The *AI-Raga* system has a provision to produce sounds in nine octaves (though this facility is not currently activated). Due to these strengths, we can explore many more facets of music. From this point of view, computers can be a blessing for Indian music. Perhaps it might help in expanding the conventional boundaries of Indian music. Computers can take music beyond human limitations. Computational music can be the beginning of a new era in Indian music.

There are multiple approaches to reconciling three realities. It is computationally favourable to use multiple mathematical formulations. The musical domain with its infinite variations does not submit easily to any one approach. While developing GTIM three main approaches are used: an axiomatic, a set-theoretic and a group-theoretic. However, when a *Bandish* is generated the context-sensitive grammar approach seems feasible. The crux of the GTIM theory is that the domain of music arises from a singularity of a musical entity called the '*Aadhar Swara*'. Therefore, various stages of the germination and growth of the domain of music are described using appropriate methodologies or approaches. Since GTIM is a computational formulation no single logical/ mathematical approach is used throughout. The pliant nature of the GTIM allows it to be extremely accurate when describing the exceedingly complex domain of Indian music.

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CHAPTER 3

Insights from the Past

Introduction

Indian music has a very rich tradition and strong theoretical foundations. There exists a lot of literature discussing the religious, socio-political and cultural dimensions of Indian music. A lot has been written on the historical aspects of Indian music as well as biographical accounts of great musicians-singers, instrumentalists, and composers (*Vaggeyakaras*) along with their genealogies and *Gharanas*. This chapter attempts to develop insights into the evolution of theoretical concepts that shaped Indian music and tries to make certain projections about future possibilities. Starting from the Vedic period, the chapter attempts to traverse the trajectory of the evolution of foundational concepts of Indian music through ancient, medieval and modern periods.

The ancient era was the era of codification of theoretical concepts of Indian music. *Naradiya Shiksha* and Bharata Muni's *Natyashastra* are considered *sutra* treatises in Indian music. *Naradiya Shiksha* is considered the authentic instructional manual for *Samaveda*. All the theoretical concepts that are used in Indian music today originated from this source or they are directly or indirectly related to the original theoretical concepts from *Samavedic* concepts. During ancient times along with *Samavedic* music, there might be a popular or *'Loukika'* music in practice however, from a theoretical perspective only *Samavedic* music was codified. The *Natyashastra* shares most of the core concepts of *Naradiya Shiksha* in the codified form with some minor variations and deviations. All the major concepts viz. *Swara* (musical note), *Grama* (group of musical notes in a *Saptaka*), *Saptaka* (musical scale), *Shruti* (microtones) etc. all originate from these two sources. It is evident that music must have been in practice for millennia before this codification happened because highly advanced concepts cannot emerge without context. This is because, for codification and theorization of any domain of knowledge, a sufficient amount of repertoire and prior scholarship should exist. Since all the theoretical concepts presented and formulated in these treatises are in highly codified *sutra* form, this era is considered the era of codification and collation of

Indian music prevalent in those days.

The *sutra* literature tries to codify then prevalent knowledge in various domains. For instance, there is Panini's *Ashtadhyayi* which codified the entire Sanskrit grammar. Pingalacharya's *'Chhanda Sutra'* tried to encode the knowledge of Vedic and poetic meters. Patanjali's *'Yoga Sutra'* is well-known for encoding and compiling the prevalent knowledge of Yoga philosophy and Yogic practices. Following is the well-known *'karika'*, a couplet that describes the salient characteristics of a *sutra*.

अल्पाक्षरं असन्दिग्धं, सारवत् विश्वतोमुखम् |

अस्तोभं अनवद्यंच, सूत्रं सूत्रविदो विदुः||

According to the above *'karika'*, a *sutra* is an aphorism that uses the minimum possible number of letters/ words, without any ambiguity, containing the very essence, embracing all meanings, absolutely faultless in nature. *Naradiya Shiksha* and Bharata Muni's *Natyashastra* are considered *sutra* treatises. Each *shloka* captures concepts and principles of music prevalent in those days in a codified manner. The concepts such as *Swara* (musical note), *Shruti* (microtone), *Grama* (group of musical notes in a *Saptaka*), *Saptaka* (musical scale), *Moorchchhana* (altered scale), *Taana* (string or a sequence of musical notes), *Shadava* (*Taana* with six notes), *Oudava* (*Taana* with five notes), *Jati System* (system of musical modes), *Vadi* ((dominant note or sonant), *Samvadi* (sub-dominant note or consonant), *Vivadi* (dissonant), *Anuvadi* (Assonant), *Graha* (starting note), *Amsha* (important note), various resting notes called- *Nyasa, Apanyasa, Sanyasa, Vinyasa, Aroha* (ascending notes), *Avaroha* (descending notes), *Varna* (aesthetically arranged notes) etc. are very clearly and thoroughly defined in these treatises.

Medieval and modern literature has tried to decode and elaborate these themes further. Most of the medieval literature in music is either based on the above treatises or inspired by these treatises. Broadly the purpose of medieval treatises was the systematic elaboration, detailing and comprehensive description with examples of the concepts and principles of *Natyashastra* as well as the elaboration and documentation of the prevalent music in the light of *Natyashastra*. For example, Sharangadeva's *Sangeeta Ratnakar* is a highly respected treatise that elaborates on the musical concepts from the *Natyashastra*. Apart from this *Sangeet Ratnakar* also tries to theorize and schematize then prevalent music and attempts to bring in systemic consistency between ancient and medieval music. For instance, the concept of *Raga* is not there in *Natyashastra* however, *Sangeet Ratnakar* smoothly integrates the prevalent practices and notions such as *Raga, Uparaga, Raganga, Bhasha, Vibhasha, Antarbhasha, Giti, Prabandha, Dhrupada,* etc. in the larger system of Indian music. Even before Sharangadeva, Matanga Muni's treatise called *Brihaddeshi,* and later on other treatises such as Damodara's *Sangeet*

Darpan follows the same tradition of theorization of Indian music. The same ethos of the tradition was continued by Pandit Venkatamakhin who developed a system of 72 *Melas* (classes of *Ragas*). In modern times Pandit Bhatkhande developed a system of 10 *Thaatas* (classes) to classify all the currently prevalent *Ragas*. This shows that the theoretical tradition of Indian music has not stagnated, on the other hand, it is evolving and responding to the needs of the time and making relevant and appropriate (*Yuganukul*) modifications while preserving the essence of the knowledge tradition.

Descriptive & Analytical Tradition

Naradiya Shiksha and Bharata Muni's *Natyashastra* are deeply codified treatises. These are known for their accuracy, precision, parsimony and devices of cross-checking the information. These can be considered as 'Encoded Knowledge Systems'. Over a period of time codified knowledge systems are further supplemented by the critical studies and analyses by later scholars. Indian music has a very rich tradition of scholastic and critical commentaries on these codified treatises. These are called *Bhashyas*. A *Bhashya* is an elaborate exposition, a commentary on the *Sutras*, with word by word meaning of each *Sutra*, their translation, together with the personal views of the commentator or the *Bhashyakara*. Abhinava Gupta's *`Abhinava Bharati'* is a highly respected *Bhashya* or a commentary on Bharata Muni's *Natyashastra.* The medieval period was mostly engaged in decoding and analyzing the *Sutras*. Sharangadeva's *Sangeeta Ratnakar* is highly descriptive while Abhinav Gupta's *Abhinava Bharati* is highly analytical. Both treatises are among the greatest hallmarks of Indian music. Both the contemporary North Indian tradition of music and Carnatic traditions of music respect and regard these treatises as common sources of knowledge. We inherit a huge *'Gyana-Samvid'* (Compendium of knowledge) for Indian music in the form of these two treatises. GTIM is deeply rooted in this '*Gyana-Samvid'* of Indian music. GTIM is greatly inspired by Bharata Muni's *Natyashastra*. The core framework of GTIM is based on the concepts and principles described in *Natyashastra*. *Natyashastra* mentions two important laws of musical consonance as '*Shadja-Panchama Bhava*' and '*Shadja Madhyama Bhava*'. These two laws are considered as the basic laws of musical inference in GTIM for instance. It will be evident from the following chapters that GTIM is an attempt to reinterpret and articulate ancient musical concepts in a formal way relevant to the new era.

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CHAPTER 4

The Ascent of *Ragas*

Introduction

The system of *Ragas* is India's unique contribution to world music. In various systems of world music, musicologists have attempted to identify and recognize popular tunes and songs, aesthetically pleasing combinations of *swaras*, beautiful melodies, phrases of musical notes, consonant pairs of notes, triplets, quadruplets of notes, and chords but they have not systematically classified them nor they have developed a comprehensive system that is comparable with the Indian system of *Ragas*. It is amazing that Indian musicologists have recognized the need for such a system and developed a system of *Ragas*. From the times of Narada Muni, Bharata Muni, and Matanga Muni to modern-day musicologists such as Pandit Venkatamakhin and Pandit Bhatkhande, they have always attempted to organize musical knowledge in general and in particular, they have attempted to organize aesthetically pleasant musical tunes, musical phrases and musical structures as a system of *Raga* in a logical manner. Their approach has been logical and rational. During Bharata Muni's times, they tried to develop a system based on the concepts called *Grama* (group of musical notes in a *Saptaka*), *Moorchchhana* (altered scales) and *Jati* (classes of musical modes). One can see the traces of these concepts in today's Indian musical practices. During Matanga Muni's times, the concept of *Raga* was understood with more clarity as compared to other earlier sources. We see a reference to the concept of '*Grama Raga*' in *Naradiya Shiksha* (1.2.7) though [Bhise, U. R., 1986, p. 82]. In the later work of Sharangadeva titled *Sangita Ratnakara*, one can see more detailed codification and more systematic articulation of the ancient tradition of the *Raga* system. Later on, due to changing socio-political and historical contexts, there emerged a North Indian system of music called the Hindustani music system and the South Indian system known as the Carnatic music system. However, in both systems of music, the concept of *Raga* remained at the core.

After Sharangadeva, Indian music was in a state of flux, names of the *Ragas* have changed, and styles of *Raga* rendering have changed, however, the concepts of *Raga* and *Tala* remained unchanged. The core of Indian music remained intact. Although, Indian music was going through a phase of transition during the medieval and late medieval era, the essential core of Indian music- the *Raga* system, *Tala* system, and the musical aesthetic understanding remained intact, probably due to its inherent musical strength. For instance, the modern-day *Ragas* such as *Malakauns, Bhairava, Bhairavi, Bhupali* and many others are the ancient *Ragas* (though the names have changed) and even today they are equally popular and have long-lasting impacts. These ancient Ragas certainly have *swara*-structures that have melodic beauty with universal appeal- surpassing the boundaries of space and time. These *Ragas* have amazing qualities to adapt to the changing taste of the audience across regions and eras.

Origins of the Raga System

Awell-known ancient treatise titled `*Manasollasa*' which is known as *Abhilashitartha Chintamani* by Someshwara describes the evolutionary sequence of musical concepts in ancient India that culminated into the *Raga* system as follows.

सामवेदात् स्वरा जाता स्वरेभ्यो ग्रामसम्भवः | ग्रामेभ्यो जातयो जाता जतिभ्यो रागसम्भवः ||
सप्त स्वराः त्रयो ग्रामा मूर्च्छनाश्चैकविंशतिः | द्वाविंशतिश्च श्रुतयः एतेभ्यो रागसंभवः ||

[Kulkarni, S. R., 1985, p. 21].

The above stanza from *Brihaddeshi* says that *Samavedic* practices resulted in the establishment of the *swara* system- a system of musical notes. That further led to the system of *Gramas* or groups of notes in a *Saptaka*. The *Jati* (classes) system originated from the *Grama* system and finally resulted in the *Raga* system. In this manner, the seven *swaras*, three *Gramas*, twenty-one *Moorchchhana* and twenty- two *shrutis* led to the *Raga* system. Thus, it seems that *swaras, Gramas, Jatis, Moorchchhana* and *shrutis* were the foundational core concepts of ancient Indian music that eventually resulted in the *Raga* system. As already mentioned in previous chapters, the GTIM is based on these core concepts of Indian music. This evolutionary sequence as mentioned in the *Brihaddeshi*, is based on the scriptural and documented evidence from music and music-related literature available during Matanga Muni's times.

Apart from the above evolutionary perspective of the origin of the *Raga* system, many musicologists widely believe that *Ragas* have a strong emotional appeal and therefore it is due to a psychological urge, people have recognized aesthetically appealing musical phrases and tunes including folk and religious songs and *mantras* and the ancient musicologists have systematically compiled them. The *Raga* system emerged out of these efforts. Some *Ragas* are pleasant, some *Ragas* are full of pathos and some of the *Ragas* evoke various emotions including love. The evocative property of a *Raga* largely depends on its musical structure and the combination of *swaras* used. Ancient Indian musicians explored the evocative possibilities of *Ragas* with various structures of *swaras* and groups of *swaras*. After experimentation and experience with repeated practice of such *swara*-structures and correlated emotions, they have arrived at the paradigm of the *Raga* system.

Brihaddeshi defines *Raga* as a group or structure of *swaras* and *swara*-phrases organized in an aesthetic manner that pleases and entertains the minds of people. The following *shloka* from *Brihaddeshi* describes this as follows.

यो ऽ सौ ध्वनि विशेषस्तु स्वरवर्ण विभूषितः| रंजको जनचित्तानां स रागःकथितो बुधैः|| (बृहद्देशी)

(*Brihaddeshi* of Matanga Muni) [Sharma, Prem Lata, 1994 edition, pp. 76-77].

Matanga Muni also further elaborates that the term *Raga* has originated from the Sanskrit root term `Ranj' (रञ्ज) which means something that results in pleasant feelings, joy, and happiness and evokes aesthetic emotions. Therefore, *Raga* can be defined as a well-organized structure of *swaras* that evokes aesthetic emotions [Sharma, Prem Lata, 1994 edition, p. 78].

The Ancient Raga System

Bharata Muni's *Natyashastra* classifies art practices in general and theatrical practices in particular into two categories - *Margi* and *Deshi*. Within the same framework of classification, ancient musical practices after Bharata were classified as *`Margi music'* and *`Deshi music'*. Matanga Muni's treatise is called '*Brihaddeshi*'. The title itself suggests that it focuses on *Deshi* music and especially *Deshi Ragas*.

Margi music had a highly codified musical structure and follow scriptural description very strictly. It follows the rules of *swara* rendering, *swara* places in an octave, *Grama*, *Moorchchhana*, and rules of ornamentation of *swara* phrases very rigorously. Musicians are supposed to adhere to these rules from the ancient treatises very strictly while rendering the *Margi* music. The practitioners of the *Margi* music are not supposed to make any changes to these rules. Probably, the rules were so designed that they take care of musical and aesthetic experience in the best possible way. *Margi* music was prevalent during Bharata Muni's times and was in vogue till the Gupta period that is till the 5th century AD. For the last so many centuries *Margi* music is not in practice. However, it is strongly believed that medieval and even contemporary classical music has evolved out of *Margi* music. *Dhrupad* style of *Raga* rendering is considered the remnant of *Margi* music. Apart from that the medieval concepts (theoretical) of *Grama Ragas, Shuddha Ragas*, and *Upa-Ragas* are believed as the derivatives of the *Margi* music.

Deshi music does not follow the scriptural rules of *swara, Grama, Moorchchhana, Shruti* etc. so strictly and does not adhere to theoretical descriptions mentioned in treatises so rigorously. The *Deshi* music is rendered and practised as per peoples' taste and cater to the regional and temporal needs of the audience. Entertainment and enjoyment of a common audience is the sole purpose of *Deshi* music. It is not averse to minimal modification of structure and *swara*-phrases. Sharangadeva in his treatise called *Sangita Ratnakara* classifies *Ragas* into various categories such as *Raganga, Bhashanga, Kriyanga* and *Upanga*. [Taralekar, G. H. , 1975, pp. 237-247].

The Raga system is highly complex and comprehensive in nature. From ancient times, through the medieval ages to modern times, it is constantly modified and updated. Its rhetoric and description have changed. Musicologists of every era have tried to capture the ethos of the *Raga* system appropriate to their era in their ways. One can see and chart out this change in terms of basic definitions of core concepts, ways of classification of *Ragas*, ways of rendering *Ragas*, and so forth. Ancient musicologists described the *Raga* system in a quite cryptic way while some other musicologists described it as a poetic and metaphorical language. During the early medieval period Sharangadeva in his *Sangita Ratnakara* uses thematic classification approach borrowing from Matanga Muni's *Brihaddeshi* and extending it further to describe the *Raga* system. He classifies *Ragas* called *Grama Ragas, Upa-Ragas, Bhasha, Vibhasha, Antar- Bhasha, Raganga, Bhashanga, Kriyanga,* and *Upanga*. One finds seeds of this classification system in Matanga Muni's *Brihaddeshi*. During the later medieval period, there was a tendency among musicologist to develop logical/ rational classification system which is more quantifiable. Eventually, it resulted in the use of mathematical methods of enumeration and classification of *Ragas*. The most evolved and robust system among them was the `*Mela*' system developed by Pandit Venkatamakhin. It is highly revered and respected in Carnatic music. This system has mathematical foundations with the rigour of musical description.

During ancient times popular and aesthetically pleasant *swara* structures were described in terms of *Moorchchhana* and *Gramas*. For example, Damodar Pandit in his *Sangit Darpana* used to describe a particular composition, they used to mention the *Graha swaras, Amsha swaras, Nyasa swaras* and the *Moorchchhana* [Kulkarni, S. R.,1985, p. 85]. This description was sufficient to know the *swaras*, their nature and their placement in the octave for a particular composition. Once the *Moorchchhana* and *Grama* are explained then the associated `*Jatis*', and *Ragas*, *swara*-phrases could be understood with ease. Probably during those days, the framework of `*Jatis*', *Moorchchhanas* and *Gramas* was well-established and well-known and therefore this system worked quite well. However, in later years, musicians explored a wide range of possibilities and the scope of music widened. It demanded more detailed description, clarity of concepts, scope, boundaries and limits of musical domains. That necessitated the need for a classification system for *Ragas*.

Evolution of the Raga System

Bharata Muni's *Natyashastra* gives a description of 18 *Jatis* and their characteristics. The *Sangita Ratnakara* of Sharangadeva, along with the description of *Jatis* also describes *Ragas*. He describes 264 *Ragas* and connects them to the ancient tradition. It seems that the concept of `*Jati*' has become obsolete after *Sangita Ratnakara*. The later writers of music do not mention `*Jatis*', however, they describe *Ragas*. For instance, *Sangit Darpan* (1625 AD) of Damodar Pandit does not mention *Jatis*. He describes *Ragas*. Probably by this time the *Jatis* were completely extinct and replaced by the *Raga* concept [Kulkarni, S. R., 1985, p. 19]. Bharata Muni's *Natyashastra* provides a detailed description of 22 *shrutis*, 7 *swaras*, *Moorchchhanas* and *Taanas* and the description of 18 *Jatis* with detailed characterization. Musicologists and scholars strongly believe that the most ancient reference to *Ragas* comes from Matanga Muni's *Brihaddeshi* which belongs to the 4th to 7th century AD though we get a reference to *Gramaraga* in *Naradiya Shiksha* which is supposed to be the earlier text. It is also strongly believed that Bharata Muni's *Jati* system, in due course of time, has evolved into the *Raga* system.

There is a debate about whether there was a *Raga* system before Bharata Muni or not but it is for certain that gradually *Raga* system became dominant and by the times of Matanga Muni, probably, it became commonplace in music. It is worth mentioning that Bharata Muni's descriptions of 22 *shrutis*, 7 *swaras*, and 18 *Jatis* remained unchallenged. But that is not the case with the *Raga* system. The following definition of *Raga* from *Sangit Darpana* of Damodar Pandit is broadly acceptable to most of the musicologists of ancient and modern times. It is as follows. Pandit Bhatkhande has quoted it in the celebrated treatise '*Hindusthani Sangit Paddhati*, Vol. 1.

स्वरवर्ण विशिष्टेन ध्वनिभेदेन वा पुनः | रन्ज्यते येन सच्चित्रं स रागःसंमतःसताम् ||

योऽसो ध्वनिविषेशस्तु स्वरवर्ण विभूषितः | रन्जको जनचित्तानां स रागःकथितो बुधैः ||

[Bhatkhande, 1998 second edition, Vol. 1, p. 8].

Originally this definition of *Raga* is found in Matanga Muni's *Brihaddeshi*. [Sharma, Prem Lata, 1994, pp. 76-77].

Broadly it means that *Raga* is a collection of *swaras* made up of *Sthayi* (stable), *Aaroham* (ascending), *Avaroham* (descending), and *Sanchari* (ascending and descending) *Varnas* (phrases) that render the picture or the visualization close to hearts of the connoisseurs. The second stanza gives a more popular definition of *Raga*. It says the *Raga* is a collection of special quality sounds or *swaras* decorated with *Sthayi, Arohi, Avarohi, and Sanchari Varnas* and that entertains and appeals to the minds of common masses. These definitions of the term *Raga* are broadly accepted by all the later writers of Indian music. However, there has been a great debate about the exact number of *Ragas* in Indian music and how to classify these, *Ragas*. There is no final word yet. *Sangita Ratnakara* describes 264 *Ragas*. Some scholars accept 36 *Ragas* while some increase this number to 84. According to Srinivas Pandit who wrote a treatise called *Raga Vibodha*, *Ragas* are infinite [Kulkarni, S. R., 1985, p. 22]. Probably, this may be understood as, there are infinite ways to entertain the audience and there are infinite permutations and combinations possible with *swaras* and above mentioned *Varnas* (ascending-descending combinations of *swaras*) and therefore there is a valid possibility of infinite *Ragas*. However, in reality, there are very limited numbers of *Ragas* practised by musicians. Even today, the number of *Ragas* documented in various treatises does not go beyond 400 *Ragas* though there are claims about more than 2000 Ragas. Just a glance at various classification systems of *Ragas* mentioned in ancient and medieval treatises show that even though the musicologists tried to classify *Ragas* in various ways, there appears a common theme that there should be few core base *Ragas* and other *Ragas* are the sub-categories of them. For instance, some of the schemes consider `*Shuddha Ragas*' and other *Ragas* as *Vikrut Ragas* and *Swaradhikrit Ragas*. Many such schemes can be mentioned: *Uttam Ragas - Madhyam Ragas*; *Mukhya Ragas - Upa Ragas*; *Janya-Janaka Ragas*; *Aashrayi-Aashrita -Ragas*; *Mela Ragas-Mela Janya Ragas* and many such schemes have been developed. [Joshi, M, 1998, *Samskriti Kosha*, Vol. 7, pp. 754-761]. However most interesting is the *Raga* and *Ragini* scheme of classification.

There has been a very strong tradition that believed in the scheme of 36 *Ragas-Raginis* of which 6 *Ragas* were considered as main *Ragas* and each of the six *Ragas* had a five *Raginis*. Most probably the number six has originated from the association of each *Raga* with each season. In the Indian context, a year is divided into six seasons. It is also assumed that classical music has origins in folk music. Folk music is a natural expression closely related to the daily life cycle of the common masses. The folk tunes appropriate to the respective season thus might have become popular among the common masses and evolved into the *Ragas*. In that sense, music tradition has been greatly successful in preserving the ethos of folk tradition. Folk music is a natural extension and expression of their seasonal activities. As a result of that the *Raga-Ragini* system has evolved. Metaphorically the main *Ragas* were considered the male *Ragas* and the sub-*Ragas* were considered as the wives of these main *Ragas* and as an extension the further sub-categories of *Ragas* were considered as *Putra Ragas* and *Putra-*

Vadhu Raginis and so forth.

Apart from the *Raga-Ragini* system, there have been attempts of connecting *Ragas* with Bharata Muni's *Natyashastra*. Dr. Amiya Nath Sanyal tried to show that the *Raga* system has evolved from Bharata Muni's *Moorchchhana* system. [Sanyal, A. N., 1959, pp.268-269]. According to him out of all the possible *Moorchchhanas*, some 18 *Moorchchhanas* are stable. Out of these 18 *Moorchchhanas* if a *sthayi* is changed to another *swara* then there will be two *Moorchchhanas* from each one. One of them will be a male *Raga* and the other will be the female *Raga* thus 36 Ragas can be generated from these 18 *Moorchchhanas*.

This chapter has been a synoptic overview of the broad outline of the development and evolution of the concept of *Raga*. The idea of *Raga* as an abstract concept, as well as the musical designs of swaras, is quite fascinating. From ancient times to medieval and modern times, *Ragas* is considered the crux of Indian musical articulations through melodic presentations. It appears that during Bharata Muni's times, the tradition of melodic music was well-settled in the form of '*Jati*' music or '*Grama Ragas*'. Probably Bharata Muni inherited it from an even more ancient tradition. Matanga Muni articulated it in a sophisticated manner in his *Brihaddeshi*. Medieval and modern musicologists explored many dimensions of this tradition articulating it in the form of *Raga-Ragini* systems or as a *Mela* system later on or as a *Thaata* system recently. The *Guru-Shishya* chain of music training preserved and consolidated the tradition till modern times. Any tradition survives and thrives due to its inherent strengths. Indian music has a robust core in the form of the concept of *Raga* but apart from that it is deeply anchored in the Indian philosophical ethos which is important.

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PART II

Mathematical Musings (Re)

CHAPTER 5

Swara, Shruti and *Saptakas*

Introduction

One of the most basic aspects of music is the organized set of pitches or tones which is known as a musical scale. The relationship among these tones or pitches has a remarkable property of being harmonious with each other from the musical point of view. There exists musical cohesiveness among all the tones of a musical scale. A musical scale is based on certain musicological or mathematical principles. As most musicians are aware, the *Saptaka* or a musical scale that is popular in contemporary Indian music has not originated in India. It has evolved in Western music and India has adopted it for more than a century. It is called the equal temperament (ET-12) scale of music. It is popular due to certain practical advantages of performing contemporary music in the West and the world over. Indian musicians too have adopted it due to its practical ease. It is very interesting to note that Western musicologists have not accepted the ET-12 scale as a theoretically and mathematically valid scale because it is not based on the laws of consonance. It is neither precise nor harmonious from a mathematical point of view [Feng, J. Q., 2012, p. 7]. There is another scale called the 'Just Intonation' scale (JI-12) which is supposed to be scientifically correct and valid from a mathematical point of view. Ironically, though JI-12 is a scientifically valid scale, it has not gained popularity because contemporary Western music uses chords extensively and chords cannot be played on the JI-12 scale. [Feng James Q., 2012, pp 8-10]. The following table provides a comparative understanding of the value differences of notes for the JI-12 scale and the ET-12 scale. All values are in Hertz.

Swaras	**Notes**	**JI-12 Scale**	**ET-12 Scale**	**Difference in Hz.**	**Bharata Muni's Respective *Swara*-Values**
Sa	C4	261.63	261.63	0	261.63
KRe	C4#	272.54	277.18	**+4.64**	278.64

Table to be continued

Re	D4	294.33	293.66	-0.67	296.77
KGa	E4b	313.96	311.13	-2.84	316.07
Ga	E4	327.03	329.63	+2.60	326.18
Ma	F4	348.83	349.23	+0.40	347.4
Mat	F4#	367.92	369.99	+2.07	370
Pa	G4	392.44	392.00	-0.44	394.06
KDha	A4b	418.60	415.30	-3.30	419.69
Dha	A4	436.05	440.00	+3.94	446.99
KNi	B4b	470.93	466.16	**-4.77**	476.06
Ni	B4	490.55	493.88	+3.33	491.3
HSa	C5	523.25	523.25	0	523.26

It can be seen in the above table that the difference between the ET-12 values and the JI-12 values is in the range of +4.64 Hz. To -4.77 Hz. It means that ET-12 values deviated from the JI-12 values on both sides quite significantly. The JI-12 scale is also called the Just scale, or Just Intonation scale because all the frequency values for musical notes in this scale are based on the harmonic series found in natural overtones. [Feng James Q., 2012, pp 8-10]. This scale has a scientific and mathematical basis. On the other hand, the ET-12 scale is a compromised tuning scheme developed for keyboard musical instruments such as the Piano. In India, ET-12 became popular because of the Harmonium which is used by most performers as an accompanying instrument in concerts. Classical musicians prefer using *Tanapura* for providing the tuning context and use violin or *Sarangi* as the accompaniment instrument though. Harmonium became popular among musicians due to its ease of use and flexibility of playing in any key.

Interestingly, the tuning system ET-12 is accepted for its practical convenience the world over. In ancient India also Bharata Muni's system of equal temperament 22 *shrutis* was highly respected. It is evident from ancient treatises that Bharata Muni's scale of 22 *shrutis* was considered a standard scale. Till the 12th century AD Bharata Muni's system was accepted and respected but later on musicologists had different views about *swara* and *shruti* positions in an octave. It is interesting to see that there is a certain merit in Bharata Muni's system of *swaras* and *shrutis*. Like the currently popular ET12 scale, Bharata Muni's scale is also an equal temperament scale as discussed in a monograph titled 'The Doctrine of *Shrutis* in Indian Music' [Vidwans V. V., 2016]). Probably that might have provided the required flexibility for musical performance in those days. In the course of the development of GTIM, it is realized that ET-12 and JI-12 scales are important but Bharata Muni's system helps in laying down the foundations for computational grammar for Indian music in a profound way. Apart from that Bharata Muni's scale provides a comprehensive musical paradigm for Indian music which is discussed in the next few sections of this chapter and the next chapter.

In the next few paragraphs detailed discussion on the genesis of the ET-22 scale, i.e., Bharata Muni's 22 *shruti* scale is given as it is immensely important for music as well as the generative logic of Indian music that is presented in GTIM. Bharata Muni's ET-22 scale can be established by various methods. In the following paragraphs, two methods are discussed. In the first method, the ET-22 scale is derived as per the description from *Natyashastra*. The second method is called the '*Chakriya Nyaya*' method. Both methods are consistent with the aural logic developed in GTIM.

This discussion is important because any musical theory cannot be developed without a discussion about the tuning systems. The GTIM takes an inclusive approach. It accepts ET-12, JI-12 (Harmonic) scale and Bharata Muni's ET-22 tuning systems as valid tuning systems. The author of this book has designed and developed an Artificially Intelligent System called AIRaga that is based on the GTIM. It has provision for generating a musical composition or a *Bandish* in all these three tuning systems. However, the GTIM is not strictly dependent on any particular tuning system. It takes Bharata Muni's ET-22 as a default tuning system for it but it is changeable. Information about the AIRaga system is provided in the appendix III.

Bharata Muni's Paradigm

As per the *Natyashastra* of Bharata Muni, \`*Gandharvam*' is a three-fold art [Brihaspati, 1986, p. 14]. It involves *Swaras* (musical notes), *Tala* (cycle of musical beats), and *Padas* (words or lyrics). The generative theory of Indian music provides a detailed description of the first and the second i.e., the *Swara* and the *Tala* components mentioned by Bharata Muni while a description of *Pada* is not the focus of GTIM theory.

Bharata Muni's *Natyashastra*, Narada Muni's *Naradiya Shiksha* and Sharangadeva's *Sangita Ratnakar* are well-known foundational treatises on Indian music. The principles and rules of the grammar of Indian music are well-articulated in these treatises. The following discussion is based on these treatises. To understand these rules authentically, the author of this book has designed and made a special musical instrument called '*Bharat Veena*'. All the concepts from these treatises can be tested and validated on this *Veena*. *Bharat Veena* is designed and developed based on the description from Bharata Muni's *Natyashastra*.

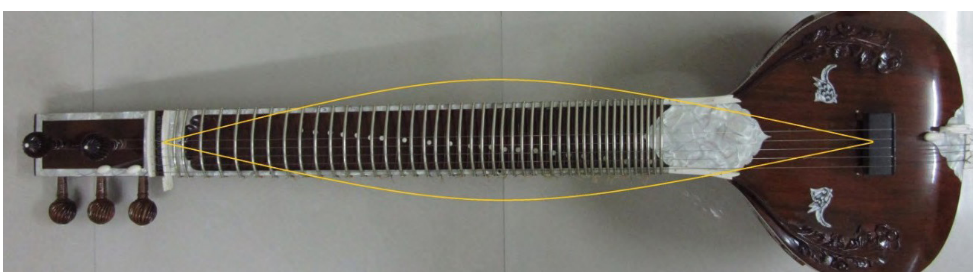
Bharat Veena

As already mentioned, we inherit all the basic concepts and principles of music from the ancient treatises. However, contemporary music has changed greatly to the extent that the ancient concepts appear to be not so relevant today. It is true in a sense that these concepts are not used as they were practised during ancient times. Bharata Muni's *Saptaka* was different from contemporary *Saptaka*. The rules of *Graha, Amsha, Nyasa, Vadi, and Samvadi swaras* are not followed any more in the same spirit. The points of difference are many. However, understanding ancient paradigms is necessary to understand the roots of contemporary music and that will also help in understanding the computational dimension of Indian music.

Swara-Sthapana & Shruti Generation

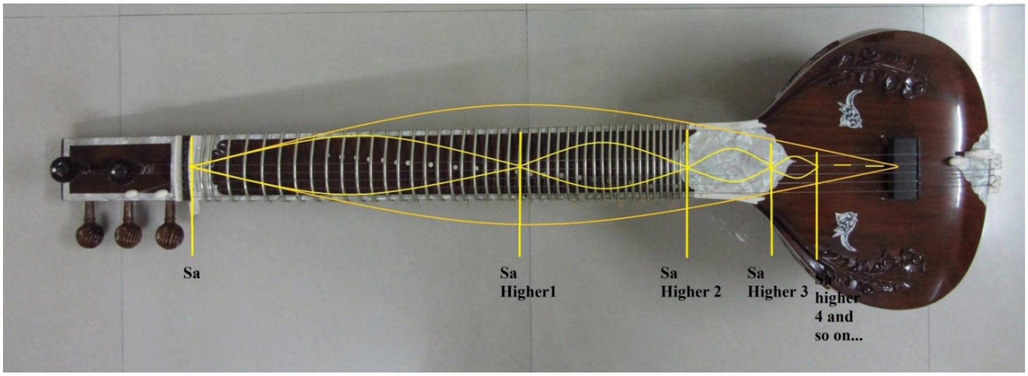
Let us begin with understanding how the *swaras* and *shrutis* were established during ancient times. Bharata Muni has provided a very clear description of establishing *swaras* and *shrutis* in the *Natyashastra*. [Brihaspati, 1986, pp. 21-34]. However, we need to interpret and decode the description systematically. Later commentaries such as *Sangit Ratnakara* of Sharangadeva help achieve the same. Following paragraphs are dedicated to explaining how *swaras* are established on the *Bharat Veena* by following the description from *Natyashastra*. But before that, we need to understand a few basic concepts about *swaras* and their positions on the *Bharat Veena*.

The entire length of the string of a *Bharat Veena* produces the natural *Sa* (*Shadja*) *swara* as shown in the following figure. For illustrations, actual photographs of the *Bharat Veena* are used.

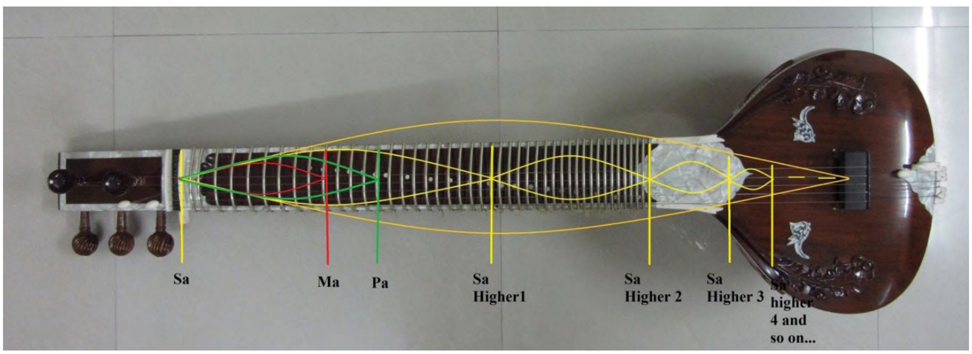


As a next step, the higher *Shadja swara* is located exactly at the mid-point of the *Veena*. Following the same ratio all the higher *Saptakas* can be established as shown in the following figure.

व्यवहारे त्वसौ त्रेधा हृदि मन्द्रोऽभिधीयते | कण्ठे मध्यो मूर्ध्नि तारो द्विगुणश्चोत्तर:| [Taralekar, G. H.,1975, Vol 1, 1-3-7, p-55]



The next step is of establishing other *swaras*. *Madhyama swara* is exactly on the mid-point between *Shadja* and the higher *Shadja swaras*. Since it is located on the midpoint, it is called the `*Madhyama*' *swara*. The *Panchama swara* is located on the point having a ratio of 3/2 between *Shadja* and the higher *Shadja swara* as shown below.



In all the above figures it is shown that the entire length of a veena represents a *Shadja swara*. However, it is not always necessary. Any point on the string can be considered as a *Shadja swara* or the *Aadhar swara* and then by applying the rules described in Bharata Muni's *Natyashastra* it is possible to establish a *Saptaka* and then twenty-two *shrutis* can be established on the *Bharata Veena*.

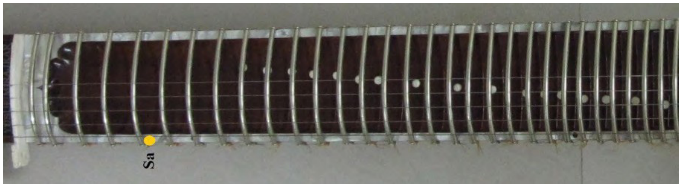
Bharata Muni's system was different from the contemporary system. It was established on the equal temperament *Shruti* paradigm. *Bharata Veena* is a '*Sama- Shruti*' *Veena*. Therefore, the value of a '*Pramana Shruti*' is a 1.032 ratio [Vidwans, V. V., 2016, p. 61]. This ratio can be validated by the '*Shruti-*

Nidarshanam' experiment mentioned in the *Natyashastra*. [Brihaspati, 1986, pp. 43-54]. The *Shadja-Madhyama Bhava* and the *Shadja-Panchama Bhava* are also based on this *Pramana Shruti* ratio. Bharata Muni's *Saptaka* and twenty-two *shrutis* are also based on this ratio. Therefore, the above-mentioned placement of *Panchama swara* and *Madhyama swara* needs to be adjusted accordingly while establishing the *Saptaka*. This needs to be clearly understood that Bharata Muni's *shrutis* were equal temperament twenty-two (ET22) *shrutis* and therefore, the ratio of 1: 1.032 is very critical. Pandit Bhatkhande in his treatise '*Hindusthani Sangit Paddhati*', Vol. IV, [Bhatkhande, V. N., Vol. IV, 1998 second edition, pp. 12-32] has thoroughly discussed this issue and concluded that Bharata Muni's *shruti*s were of equal temperament. Many researchers opposed his views and proposed the *Pramana shruti* ratio as 1: 1.0125 claiming that Bharata Muni's *shrutis* were not equal temperament *shrutis*. The author of this book has already published a monograph titled "*The Doctrine of Shrutis in Indian Music*" [Vidwans V. V., 2016, pp. 59-61] which has thoroughly discussed this issue in depth and arrived at a more convincing conclusion concurring with Pandit Bhatkhande's views that Bharata Muni's *shrutis* were of equal temperament *shrutis* and the value of *Pramana Shruti* is 1.032. The readers can refer to this monograph for more details. Parts of this chapter are based on this monograph. The following section that discusses the establishment of *Saptaka* by Bharata Muni and the experiment called '*Sarana- Chatushtayi*' is included in Appendix I which is taken from this monograph. The experiment called '*Dwividha-Moorchchhana Siddhi*' is also included in Appendix II which is also very important in this regard. Both these experiments are consistent with the Bharata Muni's equal-temperament *shruti* paradigm because both experiments succeed if and only if the Bharata Muni's *shrutis* are equal-temperament *shrutis*. These experiments fail with any proposal of a non-equal temperament *shruti* scale. Readers are requested to refer to these Appendices at the end of this book for more details about these two experiments.

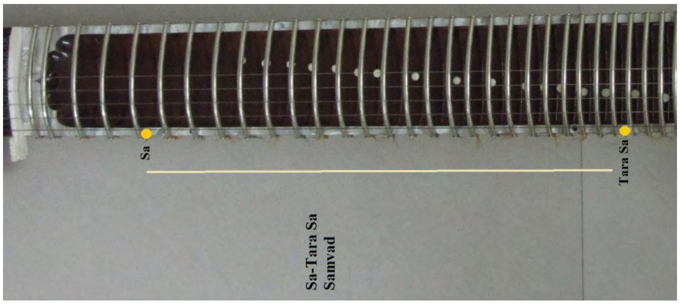
Establishing Bharata Muni's *Saptaka*

In the following paragraphs, the method for establishing Bharata Muni's *Saptaka* based on the description from *Natyashastra* is discussed [Brihaaspati, 1986, pp 21-34]. Following paragraphs explain the whole process in a step-by-step manner. Later on, the next section discusses the '*Chakriya Nyaya*' method or the cyclical method of *shruti* generation to establish twenty-two *shrutis*. The illustrative images used in the following description are the actual photographs of *Bharat Veena* for establishing Bharata Muni's *Saptaka*.

Establishing *Saptaka* on *Bharata Veena*

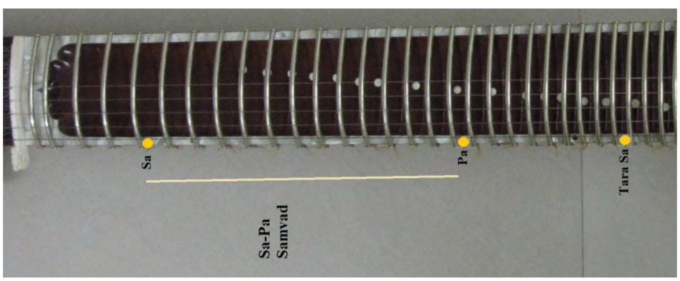


First, establish a *Vadi swara* or the *Aadhar swara* (Bharata Muni calls the *Aadhar swara Vadi* because it is useful for the *Moorchchhana* generation) on a chosen position on a string of the *Veena*. In this case, as per Bharata Muni's description, the *Vadi swara* or *Aadhar Swara* or *Shadja swara* is established on the fourth fret of the *Bharat Veena* as shown in the above figure.

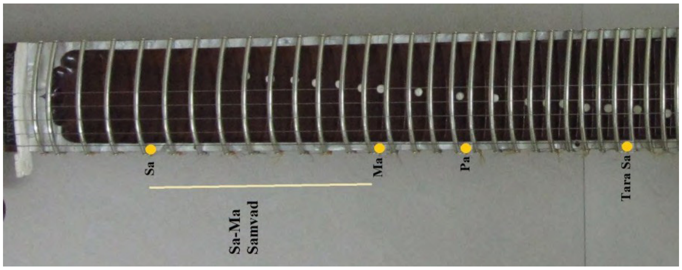


Establish *Tara Shadja swara* by using *Shadja-Tara Shadja Bhava* or *Sa*- higher *Sa* consonance. This step is not very difficult because even a novice in music can easily notice this consonance. Sharangadeva in his *Sangita Ratnakar* has already clearly mentioned this.

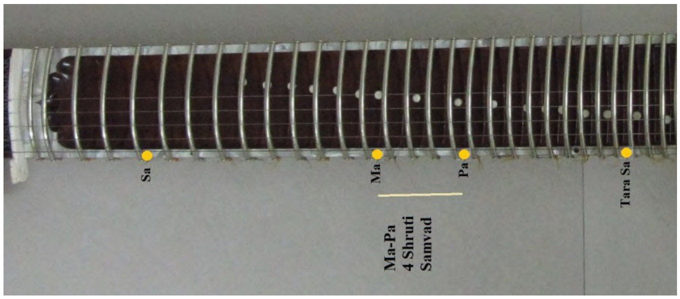
व्यवहारे त्वसौ त्रेधा हृदि मन्द्रोऽभिधीयते | कण्ठे मध्यो मूर्ध्नि तारो द्विगुणश्चोत्तर:|| [Taralekar, G. H., 1975, Vol 1, 1-3-7, p-55].



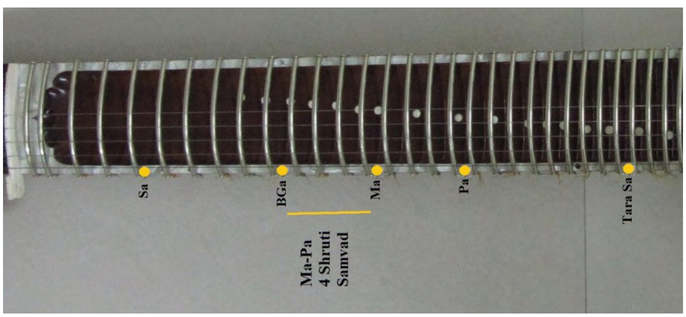
By using *Shadja-Panchama Bhava* i.e., a thirteen-*shruti* distance establishes a *Panchama swara* on the string as shown in the above photograph. Expert musicians can do this very easily due to their precise tonal sensitivity. *Natyashastra* mentions this as the 'thirteen-*shruti*' distance.



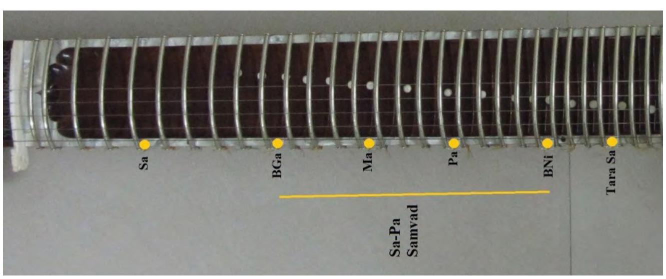
By using *Shadja-Madhyama Bhava* i.e., nine-*shruti* distance establishes a *Madhyama swara* on the string. All this is based on the Bharata Muni's description.



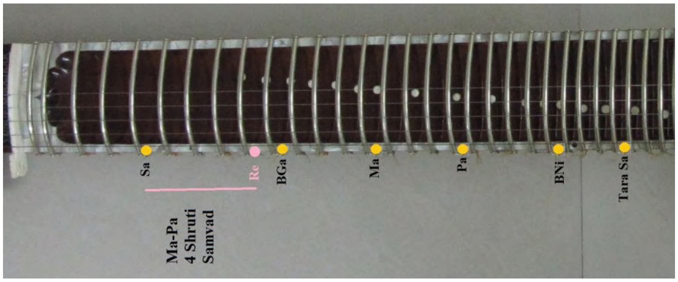
Then you get a *Ma-Pa* interval which is supposed to be of four *shruti* distance according to Bharata Muni's description.



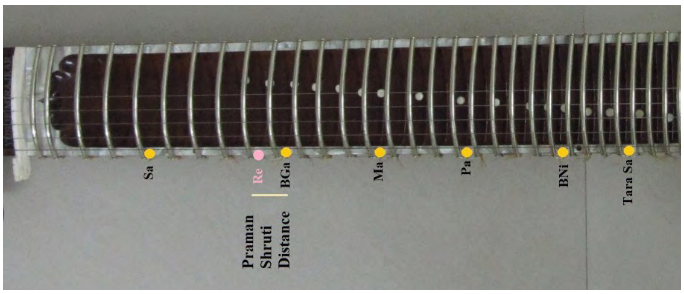
Now it is possible to establish Bharata Muni's *Gandhara* on this basis because the interval between Bharata Muni's *Gandhara* and *Madhyama* is of four *shrutis* according to Bharata Muni.



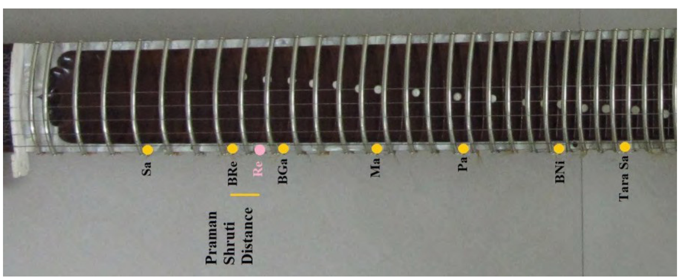
From Bharata Muni's *Gandhara*, Bharata Muni's *Nishada* can be derived by applying *Sa-Pa Bhava.* The next step is quite interesting.



It is possible to establish *Chatuh Shruti Rishabha* by following *Ma-Pa Bhava* because it is four *shrutis* away from *Shadja*. So as an intermediate step, *Chatuh Shruti Rishabha* is generated though it is not a part of Bharata Muni's *Saptaka.* The next step is even more interesting.

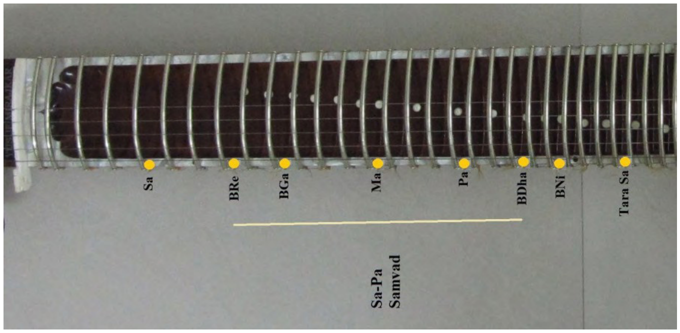


The interval between Bharata Muni's *Gandhara* and *Chatuh-Shruti Rishabha* can be judged and experienced. It is one *shruti* interval. Using this interval Bharata Muni's *Rishabha* can be generated as follows. Bharata Muni's *Rishabha* is one *shruti* lower than the *Chatuh shruti Rishabha*.

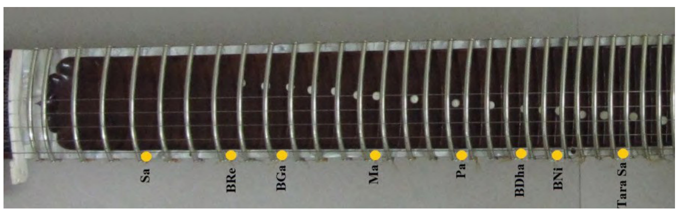


Thus *Chatuh-Shruti Rishabha* helps in inferring Bharata Muni's *Rishabha* because the interval between Bharata Muni's *Rishabha* and *Chatuh-Shruti Rishabha* is also of one *shruti*. As per the description, there is a two-*shruti* distance between Bharata Muni's *Rishabha* and Bharata Muni's *Gandhara* and *Chatuh-Shruti Rishabha* falls exactly at the midpoint between them.

[*Swaras* can be established by a few other methods as well. Once Bharata Muni's *Gandhara* is established as discussed earlier the two-*shruti* distance is distinct and easy to recognize which is a *`Vivadi'* distance. So, using this distance one can derive *Bharata Muni's Rishabha* from *Bharata Muni's Gandhara* because as mentioned by Bharata Muni the distance between *Bharata Muni's Rishabha* and *Bharata Muni's Gandhara* is of two *shrutis*.]



From Bharata Muni's *Rishabha*, by applying *Shadja-Panchama Bhava*, Bharata Muni's *Dhaivata* can be established as shown in the above image.

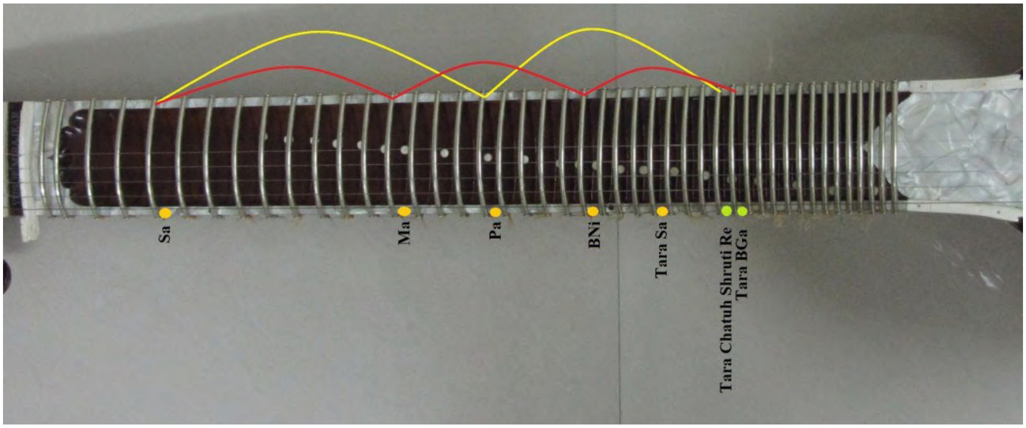


Thus, all the basic seven *swaras* of Bharata Muni's *Saptaka* can be established by using the above method. There are a few other methods for establishing a *Saptaka* on *Bharat Veena*. However, these are not discussed here for the brevity of the description. The readers can refer to the above-mentioned monograph by the author for more details in this regard.

Shruti Generation by using *Chakriya Nyaya* method

Natyashastra describes the establishment of *Saptaka* first and then mentions about 22 *shrutis*. As already shown above by using *Shadja-Panchama Bhava* and *Shadja-Madhyama Bhava* as well as *Vivadi Bhava,* we can establish a *Saptaka* of seven *swaras* in a step-by-step manner. Similarly, by using the *Chakriya Nyaya* method indicated in *Natyashastra* and elaborately discussed in *Abhinav Bharati* by Abhinav Gupta, it is possible to establish all the twenty-two *shrutis* on the *Bharat Veena*. [Kavi, M. R. and Pade, J. S., 1964, Ch. 28, pp. 15-24]. This is shown in the following paragraphs in a step-by-step manner again. According to *Natyashastra*, the *Sa-Ma* ratio is known as *Shadja-Madhyama*

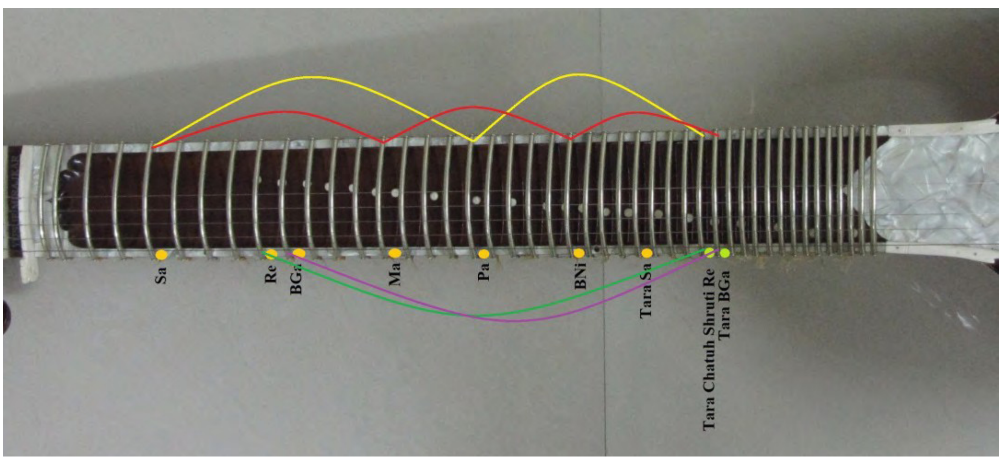
Bhava and the *Sa-Pa* ratio is known as *Shadja-Panchama Bhava*. The *Chakriya Nyaya* method is based on these two rules from Bharata Muni's *Natyashastra*. The *Chakriya Nyaya* method is also called *`Swara-Mandala Sadhanam'.*



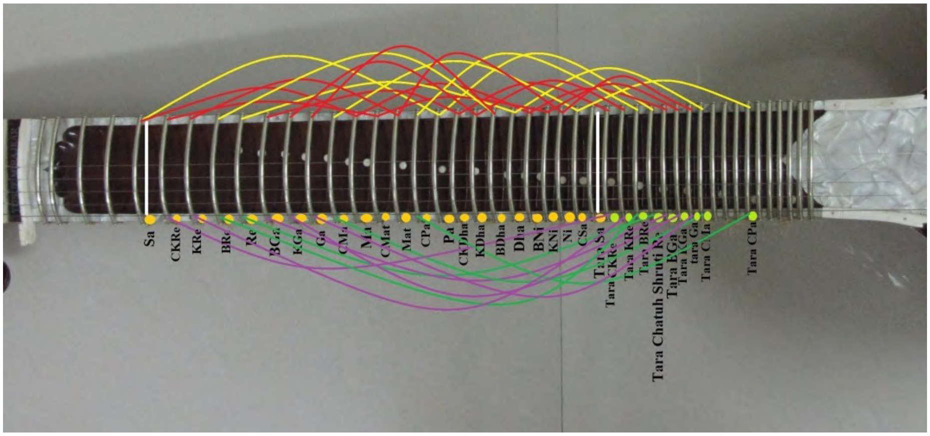
अथद्वौ ग्रामौ षड्जग्रामो मध्यमग्रामश्चेति| अत्राश्रिता द्वाविंशतिश्रुतयः स्वरमण्डलसाधिताः|

तत एव स्थानान्तरे स्वरमंडलत्वमिति चक्रमुच्यते| तच्च परिमंडलं आंगिरसकाश्यपादिभिः मुनिभिः दर्शितम् | [Kavi, M. R. and Pade, J. S., 1964, Ch. 28, p. 19].

This method was known to the ancient sages such as Aangirasa and Kashyapa. Abhinava Gupta has mentioned this method in his commentary on Bharata Muni's *Natyashastra*. The tradition has preserved this method in its collective memory and musicologists are well aware of it. The process of establishing the '*shruti- parimandala*' goes on as shown in the following images.



You start the process with the *Shadja swara* or *Aadhar swara*. Apply the *Shadja-Madhyama Bhava* and *Shadja-Panchama Bhava* to *Sa swara* and generate/ confirm *Ma swara* and *Pa swara* respectively. Then again apply both the *Bhavas* respectively to newly generated/ confirmed *Madhyama* and *Panchama swara* to get *Bharata Muni's Nishada* and higher *Chatuh shruti Rishabha* as shown in the above image. This higher *Chatuh shruti Rishabha* falls outside the bounds of a *Saptaka* so we need to bring it within the bounds of *Saptaka* by applying *Sa*-higher *Sa Bhava* in a reverse way. This whole process can be continued cyclically till you get twenty-two *shrutis*. If you continue the process, you will get the same *shruti* places again and again. Therefore, this process is called the '*Chakriya Nyaya*' method as shown below.



The entire process of establishing seven *swaras* and then twenty-two *shrutis* is based on the auditory sensitivity of a musician. The chance of making errors in establishing a *Saptaka* and *shrutis* is quite high, therefore to verify the accuracy of the *swara* places and *shruti* places in a *Saptaka*, ancient musicians have devised certain methods to cross-check and validate the *swara* positions and the *shruti* positions on the *Veena*. One of the well-known methods is called the '*Shruti-Nidarshanam*' experiment or '*Sarana-Chatushtayi Prayoga*' as already described.

From the above sections, the readers will understand that the rules of the grammar of Indian music have computational qualities and how their manifestation leads to the generation of musical entities. An important aspect of this discussion is that there exists an inherent generative logic, foundational to these rules. A unique characteristic of the generative grammar is that from one base entity called *Shadja swara,* by applying a few basic rules, *Shadja-Madhyama Bhava* and *Shadja- Panchama Bhava* in the case of Bharata Muni's scale, all the other musical entities (*swaras* and *shrutis* etc.) can be generated. This is precisely the reason why it is termed as a 'generative grammar'.

Artistic creations have profound computational foundations in Indian arts. The computational foundations enhance the quality of aesthetic experience. They also, facilitate the process of aesthetic experience. There exists a correlation between artistic computation and the aesthetic experience. In this book, this is demonstrated by analyses of concepts from Indian music. It is fascinating to see that underneath the evocative ability of Indian music, there are quantitative and computational principles. In other words, a 'Computational Grammar of Music' makes the musical aesthetic experience possible. It is interesting to see how these rules that are computational in nature play an active role and contribute to the generation of music that leads to an aesthetic experience.

Bharata Muni's scale and Contemporary Scale- A comparative Study

From the above description, it must be noted that Bharata Muni's *Saptaka* was different from the contemporary *Saptaka* that is used in music presently. Contemporary music has much deviated from ancient music in terms of *swara* positions, *shruti* positions and the nomenclatures of the *swaras* in a *Saptaka*. However, the basic philosophy and foundational concepts of *swara, shruti,* and *Saptaka* remain the same. It will be a good idea to give a brief summary of ancient *swaras, shrutis* and *Saptaka* and compare them with contemporary practices. Bharata Muni's *Saptaka* had seven *swara*s as {sa, bre, bga, ma, pa, bdha, bni}. Here bre is Bharata Muni's *Rishabha*, bga is Bharata Muni's *Gandhar*. Bdha is Bharata Muni's *Dhaivata* and bni is Bharata Muni's *Nishad swara*s. These four *swara* positions were different as compared to contemporary re, ga, dha, and ni *swara*s. The contemporary *Saptaka* that is based on the popular ET-12 scale has a different set of seven *swara*s as {sa, re, ga, ma, pa, dha, ni}. The following sets of respective scales will give a good idea about both scales. Throughout this book the value for *Shadja swara* is taken as 240 Hz. because that was the earlier convention in Western music and Pandit Bhatkhande has taken this value as a reference value for *Shadja swara* in all his writings. To maintain the scholastic tradition of writing, the same conventional values are followed in GTIM. Traditional Indian musicians and musicologists are quite familiar with this convention. Accordingly, Bharata Muni's ET-22 scale with 240 Hz. as the frequency value of *Shadja* swara will be as follows.

ET-22 = {**240**, 247.68, ***255.6***, 263.79, **272.23**, 280.94, ***289.94***, **299.22**, 308.79, **318.68**, 328.88, ***339.41***, 350.27, **361.48**, 373.05, ***384.99***, 397.32, **410.03**, 423.16, ***436.7***, **450.68**, 465.11, 480}.

The following table captures the ET-22 values and ET-12 values for comparison.

Bharata Muni's *Shrutis*	ET-22 Values in Hertz	Bharata Muni's 7 *swaras*	Contemporary 12 *swaras* as per ET-22	ET-12 *swaras*
Sa	**240**	**240** (Sa),	**240**	240
CKRe	247.68			

Table to be continued

KRe	***255.6***		***255.6***	254.27
BRe	263.79	263.79 (BRe)		
Re	**272.23**		**272.23**	269.39
BGa	280.94	280.94 (BGa)		
KGa	***289.94***		***289.94***	285.41
Ga	**299.22**		**299.22**	302.38
CMa	308.79			
Ma	**318.68**	**318.68** (Ma)	**318.68**	320.36
CMat	328.88			
Mat	***339.41***		***339.41***	339.41
CPa	350.27			
Pa	**361.48**	**361.48** (Pa)	**361.48**	359.59
CKDha	373.05			
KDha	***384.99***		***384.99***	380.98
BDha	397.32	397.32 (BDha)		
Dha	**410.03**		**410.03**	403.63
BNi	423.16	423.16 (BNi)		
KNi	***436.7***		***436.7***	427.63
Ni	**450.68**		**450.68**	453.06
CSa	465.11			
Sa (Higher)	480	480	480	480

Generally, the frequency value of *Shadja swara* is taken as 261.23 Hz. due to the MIDI standards so that modern musicians understand these values easily. Therefore, in the context of MIDI standards if the value of the *Shadja swara* is taken as 261.23 Hz. then the comparison between Bharata Muni's *shrutis/ swaras* and the ET-12 *swaras* will be as follows.

Bharata Muni's Shrutis	**ET-22 Values in Hertz**	**Bharata Muni's 7 *swaras***	**Contemporary 12 *swaras***	**MIDI ET-12 *swaras***
Sa	**261.63**	261.63 (Sa),	**261.63**	261.63 (Sa)
CKRe	270			
KRe	***278.64***		***278.64***	*277.18 (KRe)*
BRe	287.56	287.56 (BRe)		
Re	**296.77**		**296.77**	293.66 (Re)

Table to be continued

BGa	306.26	306.26 (BGa)		
KGa	***316.07***		***316.07***	*311.13 (KGa)*
Ga	**326.18**		**326.18**	329.63 (Ga)
CMa	336.63			
Ma	**347.4**	347.4 (Ma)	**347.4**	349.23 (Ma)
CMat	358.52			
Mat	***370***		***370***	*369.99 (Mat)*
CPa	381.84			
Pa	**394.06**	394.06 (Pa)	**394.06**	392.00 (Pa)
CKDha	406.67			
KDha	***419.69***		***419.69***	*415.30 (KDha)*
BDha	433.13	433.13 (BDha)		
Dha	**446.99**		**446.99**	440.00 (Dha)
BNi	461.3	461.3 (BNi)		
KNi	***476.06***		***476.06***	*466.16 (KNi)*
Ni	**491.3**		**491.3**	493.88 (Ni)
CSa	507.03			
Sa (Higher)	523.25	523.25	523.25	523.25

The *swaras* Re, Ga, Dha, and Ni have different positions in the Bharata Muni's *Saptaka* during ancient times as compared to the ET-12 scale. Bharata Muni's *Rishabha* (287.56) was approximately one *shruti* lower than the *Rishabha* (296.77) of the contemporary scale. Bharata Muni's *Gandhara* (306.26) was approximately one *shruti* lower than contemporary *Komal Gandhara* (*316.07*) and can be considered as *Ati-Komal Gandhara* in today's context. Similarly, Bharata Muni's *Dhaivata* (433.13) and Bharata Muni's *Nishada* (461.3) were approximately one *shruti* lower than the contemporary *Dhaivata* (440) and contemporary *Komal Nishada* (*466.16*) respectively. Bharata Muni's *Panchama* (394.06), and *Madhyama* (347.4) were approximately closer to the positions of contemporary *Panchama* (392.00) and *Madhyama* (349.23) respectively.

The Just Intonation Scale:

Based on the perception of harmonic relationships between frequencies having simple harmonic ratios sound pleasant and good to our ears. The just intonation scale is a natural result of the 'overtone series' of a vibrating string or vibrating air columns of musical instruments [Feng, J. Q., 2012, pp. 8-9]. There are at least two or three different opinions about the 'Just Scale'. The JI Scale provides around 17 frequencies for 12 positions in an octave. It seems there is no consensus about the *swara* positions in JI as against the ET-12 *swara* positions. Following are the ratios for the JI scale as recommended by musicologists.

JI Ratio = {1/1 (Sa), 25/24, 16/15 (KRe), 10/9, 9/8 (Re), 6/5 (KGa), 5/4 (Ga), 4/3 (Ma), 45/32 (Mat), 64/45, 3/2 (Pa), 8/5 (KDha), 5/3 (Dha), 7/4, 16/9, 9/5 (KNi), 15/8 (Ni), 2/1 (Higher Sa)}.

Based on these ratios we get the following frequencies.

JI = {240 (Sa), 250, 256 (KRe), 266.66, 270 (Re), 288 (KGa), 300 (Ga), 320 (Ma), 337.5 (Mat), 341.333, 360 (Pa), 384 (KDha), 400 (Dha), 420, 426.66, 432 (KNi), 450 (Ni), 480 (Higher Sa)}.

This is presented in a tabular form as follows.

***Swara* Names**	**Ratios for JI Scale**	***Swara* Values in Hz.**	**Remarks**
Sa	1/1	240	
KRe	25/24	250	Extra lower KRe
KRe	16/15	256	
KRe?	10/9	266.66	Too close to Re
Re	9/8	270	
KGa	6/5	288	
Ga	5/4	300	
Ma	4/3	320	
Mat	45/32	337.5	
Mat	64/45	341.333	
Pa	3/2	360	
KDha	8/5	384	
Dha	5/3	400	405 Dha?
KNi?	7/4	420	Extra lower KNi
KNi	16/9	426.666	
KNi	9/5	432	
Ni	15/8	450	
Higher Sa	2/1	480	

The discussion about *swaras* and *shrutis* gives a feeling that there is no unanimity about the positions of *swaras* and *shrutis*. It is true in a certain sense because even in Western music there is no unanimity about the frequencies of musical notes. ET-12 scale is a brute-force compromised solution. There are many proposals from different points of view. The Just Intonation (JI) scale is supposed to be the scientific one, however, they also have proposed around 17 positions of notes that are pleasing frequencies. It becomes very difficult to match them with the 12 *swara* positions of the ET-12 scale. In a very strict sense, the *swara* positions of these popular scales do not match with each other. This remains an unresolved issue for musicologists. However, as the world music is settled down for a practical solution of ET-12 scale, in the Indian context Bharata Muni's ET-22 *shruti* scale appears to be the best possible solution to the problem of *shrutis* since Indian music is known for its microtonal richness.

As a summary of this chapter, it may be said that Bharata Muni's scale of 'seven *swaras'* can be established by the procedure given in the *Natyashastra.* Similarly, Bharata Muni's equal temperament twenty-two *shruti* scale can be established by the procedure of '*Swara-Mandala Sadhanam*' or the '*Chakriya-Nyaya*' method as discussed. The results of both processes can be validated by the '*Shruti-Nidarshanam*' experiment and by the '*Dwi-Vidha Moorchchhana Siddhi*' experiment that is mentioned in the *Natyashastra* (both the experiments are provided in Appendix I and Appendix II). There exists a logical consistency in the theoretical treatment of the process of the generation of *swaras* and *shrutis* in the *Natyashastra*. Therefore, the equal-temperament twenty-two *shruti* paradigm of Bharata Muni is theoretically consistent and logically robust. The ET-12, JI-12 and ET-22 scales are very important in their way as discussed. The next chapter introduces a new scale which is similar to the JI-12 scale based on the principles of consonances.

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CHAPTER 6

Consonances and Harmonic *Swaras*

Introduction

Every entity in nature has its frequency by which it vibrates. Any vibration is a complex natural phenomenon. When it is said that an object has a natural frequency, it is never a single frequency. It is a complex collection of harmonics, upper partials, formants, and the dominant frequency of the object. When a string is plucked it produces a sound that has all the above-mentioned components. However, the frequency that is loud and dominant is considered the natural frequency of the string. The characteristic quality of the sound is dependent on the material properties of the object that produces the sound. This characteristic quality of the sound is called the 'Timbre' of the sound. The sound of a string is an outcome of the act of plucking the string, the tension in the string, the force applied, the material properties of the string and the medium or the atmosphere around the string. The human voice is highly complex because it is produced by multiple vocal cords. Due to these complexities, any sound that is produced has a unique character dependent on the above-mentioned factors. From a musical point of view, the frequency, volume, and timbre of the sound are very important. However, out of these three properties, the dominant frequency and the collection of strong harmonics around it are important because they have a seminal role in music generation. The set of harmonics around the dominant frequency is not a random collection of frequencies. It is an organized and structured collection of frequencies following the laws of physics. All the harmonics and the partials have definite mathematical relationships with the main frequency. Harmonics and partials also have definite relations among themselves. These relations can be understood in terms of the ratios of these frequencies. The moment a sound is produced, along with the dominant frequency, volume, harmonics and these mathematical ratios or relationships are expressed.

Most dominant and musically significant ratios are already identified in Indian music as well as in Western music. Whenever we talk about the frequency of the sound, we should be aware of the fact that it is not just the frequency but along with it exists a set of musically significant ratios. Some of these ratios are known as *Shadja-Panchama Bhava, Shadja-Madhyama Bhava* and *Shadja- Gandhara Bhava* in Indian tradition. These ratios are considered the laws of the aural inference process in the generative theory of Indian music (GTIM) which will be discussed at an appropriate place. It is highly insightful that when a sound is produced, apart from the volume and timbre of the sound, two musically significant aspects that is the dominant frequency and a set of the laws of aural inferencing are expressed. They are inherently there. GTIM attempts to articulate the inherent structure of the musical sound and present it in a formalized manner. The main frequency and the set of laws of aural inferencing are the foundation stones of the logic of music. It does not mean that other aspects of sound such as volume or timbre have no role in music. These aspects of sound are important and they have definite and specific roles in music generation that will be discussed at appropriate place in the course of discussion. It may be said that these factors have a secondary role while dominant frequency and the set of the laws of aural inferencing have the primary role in Indian music. It will be pertinent to say that the entire music originates from these two aspects of sound- frequency and the laws of aural inferencing. In strictly scientific terms these laws are nothing but consonances. The following sections, therefore, discuss the nature of these consonances.

Consonances

We can describe the sound as a wave, an oscillation of pressure and density in the air that carries energy. This oscillation causes a continuous transfer of energy. The oscillations of the source displace adjacent particles, these displaced particles move away from the source, causing a reduction in pressure which is termed as a 'rarefaction'. This reduction in pressure is unstable, therefore the surrounding air pushes back in causing a sudden influx of air in the rarefied region, this is called a 'compression'. This compression necessitates a rarefaction in the surrounding air. This causes a chain of compressions and rarefactions which propagate through space in spherical wavefronts. Surely the long melodious notes of a singer, the lilting melodies of a *Santoor* or even birdsongs have little in common with the screeching of tires on a highway, or the blaring of a siren. From a mathematical perspective, all these instances are treated identically, though they are perceived quite differently by the human ear. The theory of consonance is therefore required to explain and quantify the difference between symphony and cacophony.

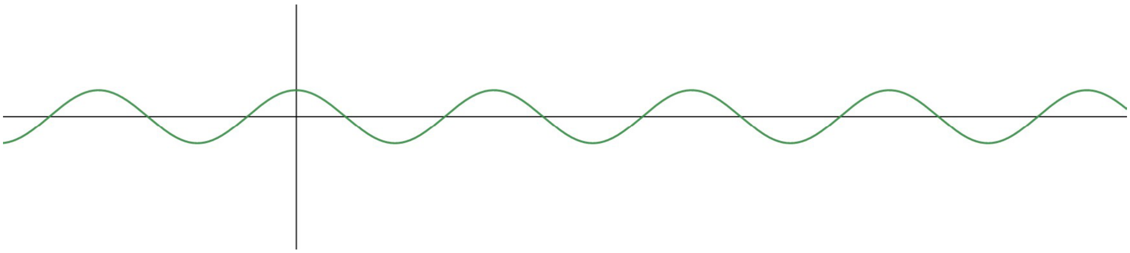
The Wave Equation and the Principle of Superposition.

The wave equation for a standing wave (the kind of wave that is generated on a string) can be represented as $y(x,t)=A\sin(\omega t)\cos(kx)$
Where,
$\boldsymbol{\omega}$ is the angular frequency
k is the angular wave number. (Also called the 'linear frequency')

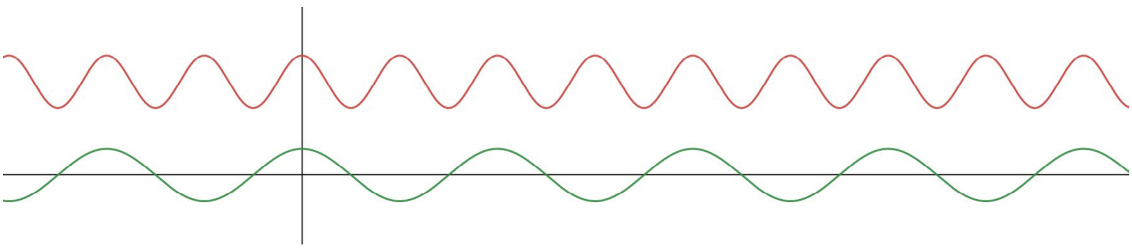
A is the amplitude,
t is time
x is the distance from source

This equation represents the displacement of a particle at time t and distance x from the source. We may get acquainted with various properties of this equation by substituting in value for ω and k.

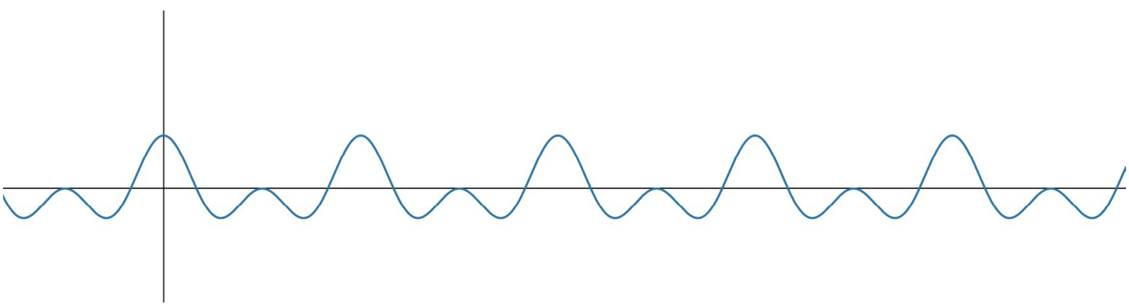
Putting $\omega = \omega_0$ and $k = k_0$, we get the following wave (at $t = 1$).



Putting $\omega = \omega_0$ and $k = 2k_0$, then we get the same wave but squished by a factor of 2. This represents a frequency exactly one octave higher than the original.

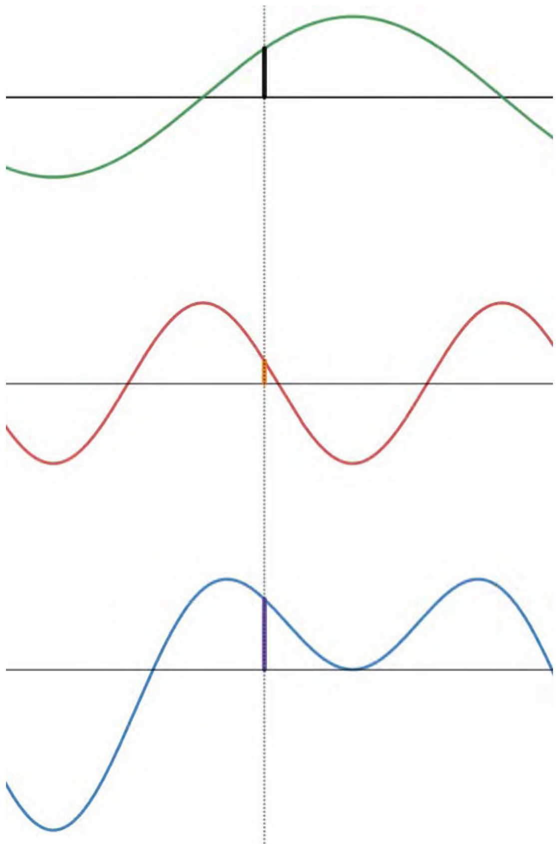


Now suppose we sound both these waves together; we get the following waveform.



Now we can see the principle of superposition in action. If we take the two constituent waves and simply add them together, we get the resultant waveform!

This is demonstrated through a close-up view of all three waveforms together.



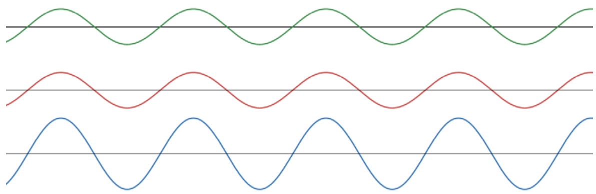
The sum of the displacements marked in **orange** and **black** is exactly equal to the displacement marked in **violet.**

Therefore, we may state the principle of superposition as follows, "The resultant displacement due to multiple waves is the sum of the individual displacements of the constituent waves"
Or more formally,
If y_r is the resultant displacements due to waves $y_i \;\; i \in N$ then
$y_r = y_1 + y_2 + y_3 \cdots y_n$.
The principle of superposition also states that if a series of periodic functions are summed, then the resultant function will also be periodic. Thus, combining frequencies is as simple as mixing paints on the palette! It is also possible to 'unmix' these paints, that is, it is possible to derive the constituent frequencies of a signal from the final waveform. This is the foundation of Fourier Analysis although we need not go into these details in the context of GTIM.

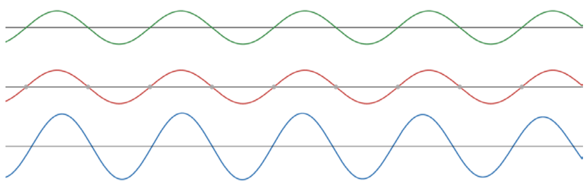
The Types of Interference

The phenomenon of interference of sound waves is important to understand consonances and dissonances. When two waves meet at a point, they are said to 'interfere' with each other. This interference can be either 'constructive' or 'destructive'. Constructive interference occurs if the amplitude of the resulting motion is greater than that of either wave. This may be seen through various examples.

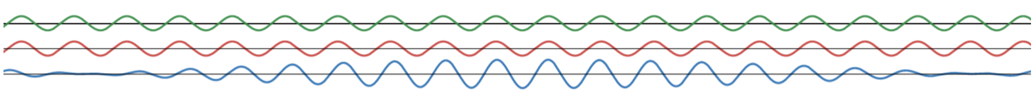
1) Completely Constructive Interference: Both waves arrive perfectly in sync and reinforce each other. The resulting wave has an amplitude equal to the sum of the constituents. The period of the resultant is same as that of the constituents.



2) Partially Constructive/Destructive Interference: Two waves interfere slightly out of phase; the resultant wave has a pseudo-period nearly equal to that of the constituents but a true period that is much longer.



   Notice that the apparent period of the resultant is nearly the same as that of the constituents. However, the true period is actually much longer and also involving some element of destructive interference, as can be seen by zooming out.



   Notice how the resulting wave tapers off towards the end.

3) Completely Destructive Interference: - The waves arrive completely out of phase and cancel each other out. The resulting waveform is a flat line.

Consonances and the Perception of Sound

Consonance can be defined from a musical perspective as the harmonious combination of two waves. The harmonious combination of frequencies appears pleasing to our ears. The term 'harmonious' lends a certain element of subjectivity to this definition. Hence this term must be explained and supplemented with physical and mathematical criteria to facilitate an objective distinction between consonance and dissonance. Research conducted by the physicists George Simon Ohm, and Hermann von Helmholtz, in the mid-nineteenth century, appeared to indicate that the ear functions like a rudimentary Fourier Analyzer. It seemed that the ear was able to break down a complex sinusoidal wave into its constituent harmonics. This characterization was later discovered to be an oversimplification and modern research has shown it to be quite inaccurate. The leading authority on psychoacoustics W. D. Ward stated that the ear functions in this manner in only certain restricted conditions. This is thoroughly discussed in the chapter titled 'Musical Perception' in the book 'Foundations of Modern Acoustic Theory' by Jerry Tobias. [Tobias J., 1970]. Even so, this characterization is a useful abstraction to understand the science behind the musical phenomenon. It also helps when it comes to ascertaining and understanding the phenomenon of consonances. We must also note that consonance is a relative term. It may only be used when comparing two intervals.

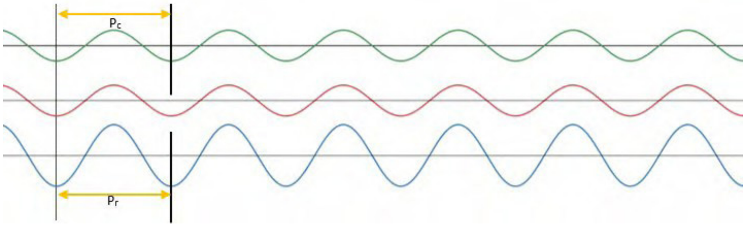
Whenever a single frequency is sounded, the ear infers its higher integer multiples (called harmonics). When two frequencies are sounded, the ear infers these harmonics for both frequencies. If the harmonics of both frequencies coincide, then they reinforce each other. The greater the regularity of these reinforcements, the more consonant the two frequencies are. This is the fundamental premise of the theory of consonance.

Therefore, it is obvious that any musical note is most consonant with itself. Hence, two notes having the same frequency, played at the same time possess the maximum possible degree of consonance. This aspect is considered the core of musical logic and the axiomatic system developed in GTIM. These aspects of consonances are discussed in a dedicated chapter on the logical foundation of Indian music in this book.

The phenomenon of consonance may also be understood in terms of the periods of the resultant waveforms. The ear perceives a single sinusoidal wave as a 'pure tone'. If the resultant waveform of two interfering waves has a period of similar length to the pure tone, then the ear cannot distinguish between the period of the resultant and the period of the pure tone and thus perceives them as a consonant. This is discussed in a research paper titled 'Harmony Perception by Periodicity Detection' [Stolzenberg, F., 2016].

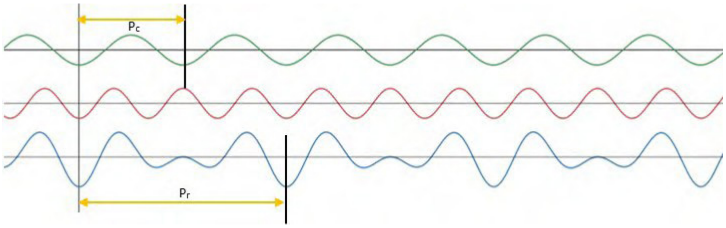
However, if the resultant waveform of two interfering waves has a large period, the ear perceives this large period as a regular variation of volume, this phenomenon is known as the 'acoustic beat'. Classical Music considers the acoustic beat to be dissonant. The phenomenon of beats is relevant in the discussion on music but currently, that is not the focus of this chapter. However, we may first understand the phenomenon of consonance through a qualitative perusal of pressure versus time plots as follows.

Consider the case of a pure tone sounding with itself as follows. The resultant waveform has the same period as the constituent pure tones. This phenomenon is theorized as the first axiom of GTIM which will be discussed later on.



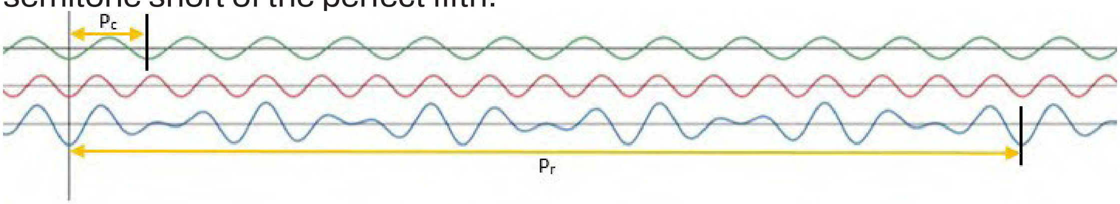
Pr = Pc. Therefore, both periods are equal.

Now, we consider the example of a perfect fifth, this is considered the second (or third, it is a matter of some debate) most consonant interval. This results in the second axiom of the GTIM which will be discussed later on.



Here Pr = 2Pc. Therefore, the period of the resultant is twice the period of the constituent. Thus, the ear still does not hear the pulsating associated with dissonance and acoustic beats.

There are a few more instances of consonances of lesser degree but they are not discussed here. Now we consider an example of dissonance as follows. We may take as a reference the shrill tritone, an interval of 6 semitones, just a semitone short of the perfect fifth.



As we can see, Pr >> Pc. Therefore, the ear perceives this as a dissonant interval. The phenomenon of periodicity detection was first observed in 1983 by G. Langer. [Langer, G., 2015]

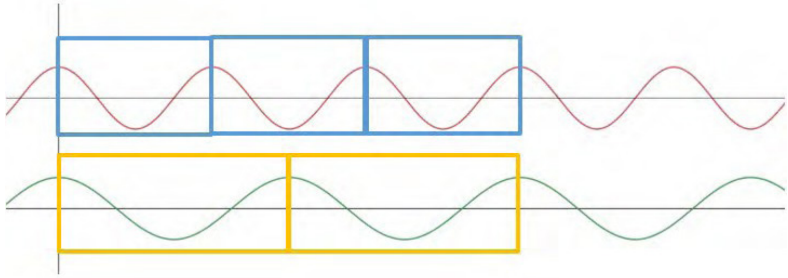
Consonances and Indian Music

This discussion has, until this point, focused entirely on the resultant waveforms when two notes are played simultaneously. However, traditional Indian music is predominantly a melodic tradition, vocal or instrumental. One may therefore reasonably ask the question as to whether the present discussion on consonance applies to the Indian musical canon. This question leads us, to an unexplored territory in the Indian context- 'implied harmony'. We know the role of the *Tanpura* in setting the harmonic context for musical performance. This will be discussed in more detail in the next chapter. The droning notes of the *Tanpura* establish the scalar harmony with the tonic *swara* in which performance is rendered. In a typical mehfil (concert) the *Tanpura* player plays the tonic and the dominant of a scale that is *Shadja swara* and the *Panchama* or *Madhyama swara* respectively. The melody sung (or played) by the performer is unconsciously perceived and analyzed against this harmonic context. Therefore, if a note aligns with the tonic/ subdominant, and its harmonics then that note will sound harmonious and its melodic character will also be greatly enhanced. If by contrast, a note is dissonant with the harmonic context, then that note will sound out of place or out of tune. This harmonization with the *Tanpura* may be called 'harmony with droning notes' or consonance with droning notes. This represents the first of the two instances where consonance is established. The second instance of consonance may be called an 'instantaneous induced harmony'. For this, we need to first explore the role of the 'sounding boards' of instruments. In India, the traditional process of making a *Veena* consists of seasoning specially grown gourds or a *Tumba* that function as sounding boards for the *Veena* or other string instruments. The main purpose of these gourds is to enhance the volume of the sound produced. However, the acoustic properties of these gourds also entail that a note appears to last longer than its actual duration. This longer-lasting note functions (instantaneously) as a base note for the succeeding note. Therefore, we may say that for a short instant, after it is played, the note induces harmony or consonance. If the succeeding note aligns with this instantaneously induced harmony, then the transition sounds favourable, otherwise, it generates tension and so the dissonance. Therefore, we may conclude that Indian music relies on 'implied harmony'. This 'implied harmony' consists of an established harmony with the droning notes of the *Tanpura* and an instantaneous harmony with the preceding note.

A Graphical Method of Representing Consonance:

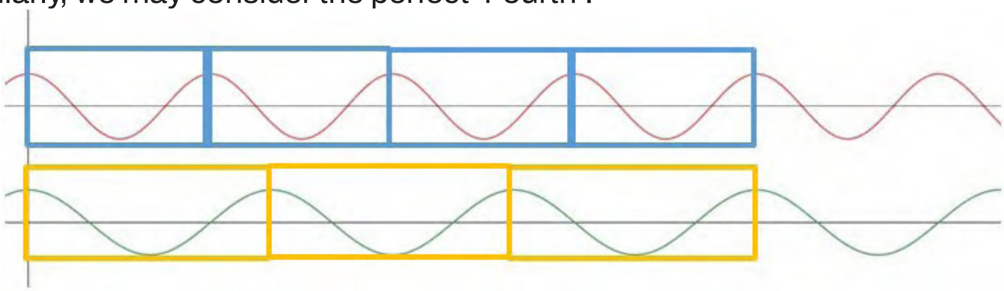
Pythagoras who formulated the theory of consonances in the West surmised that consonant frequencies were those that were rational multiples of the base frequency. This phenomenon is already discussed while discussing the Just Intonation scale- JI-12 in the previous chapter. Therefore, the 'perfect fifth' or the *Shadja-Panchama Bhava* is 3/2 times the tonic whilst the 'perfect fourth' or the *Shadja-Madhyama Bhava*, 'major third' or the *Shadja-Gandhara Bhava*, 'major second' or the *Shadja-Rishabha Bhava* are 4/3, 5/4, 9/8 times the tonic respectively. Pythagoras also stated that the order of consonances depended on how 'simple' these fractions were. Thus, the fraction 3/2 was deemed 'simpler' than 4/3 and hence the 'Fifth' was more consonant than the 'Fourth'. This theory, even though belonging to classical antiquity, enjoys a blessing with our aforementioned analysis of waveforms. Recall that consonance was a direct consequence of the regularity with which perfectly constructive interference was achieved. The simplicity and beauty of the Pythagorean ratios are a direct consequence of this affinity toward regularity. It may be explained lucidly by considering some examples.

Consider the perfect fifth.



Notice that perfectly constructive interference recurs after exactly three cycles of the first waveform and exactly two cycles of the second waveform. This is indeed a manifestation of the 3:2 ratio.

Similarly, we may consider the perfect 'Fourth'.



Here we see how the ratio of 4:3 is expressed. Exactly 4 cycles of the first waveform correspond to 3 cycles of the second. As already mentioned, the ratio of 3/2 and

4/3 are traditionally known as *Shadja-Panchama Bhava* and *Shadja-Madhyama Bhava* respectively. These are called *Samvad Bhavas* and are considered the third axiom of the logical system in GTIM. That will be discussed in the chapter dedicated to the logical foundations of Indian music.

Perfectly constructive interference, as discussed in the second case, occurs slightly later than in the first example. Consequently, the period is longer and hence this interval is less consonant than the perfect fifth. The less simple the ratio, the more dissonant the interval. In the same way, the graphical representation is possible for the 'major third' which is the *Shadja-Gandhara* relationship and the 'major second' which is the *Shadja-Rishabha* relationship as per the Indian tradition.

Harmonic *Swara* Scale

After comparative studies of various consonances between and among *swaras* and *shrutis,* the author of this book has come up with a mathematical formulation to establish the 12 *swara* scales. This is a consonance-based *swara* scale that deserves certain merit in the GTIM. These *swara* positions are very close to the JI-12 scale *swara*s in some sense but based on a completely different formulation. The above-mentioned graphically represented consonances can be understood from a mathematical point of view. Specifically, they can be understood based on the ratios of 'Arithmetic Mean' and 'Harmonic Mean'. The 'perfect fifth' or the *Shadja- Panchama Bhava* can be articulated by Arithmetic Mean while the 'perfect fourth' or the *Shadja Madhyama Bhava* can be represented by the Harmonic Mean. (Interestingly, the *Teevra Madhyama Bhava* can be expressed by a Geometric Mean.) For any given pair of *swaras,* their Arithmetic Mean is always a consonant *swara*. In the case of an octave, it is the *Panchama swara*. Similarly, for any given pair of *swaras,* their Harmonic Mean is always a consonant *swara*. In the case of an octave, it is the *Madhyama swara*.

If these two ratios are applied to the base frequency of an octave which is a *Shadja swara*, systematically then it leads to all the 12 *swaras* of the scale. Throughout this book, these 12 *swaras* are used to represent the 12 *swara* scales called the 'Harmonic Scale'. In the next few chapters, it is also shown that these 12 *swaras* are easily integrated with the Bharata Muni's paradigm of 22 *shrutis*. In a way these *swaras* are derived by a generative mechanism and up to 18 *swaras* can be derived that may be integrated into Bharata Muni's scale.

This is an interesting mathematical phenomenon that gives a deeper insight into the correlation between physics, mathematics and music. By applying the ratios of arithmetic mean and harmonic mean it can be shown that the rest of the *swara* relations and the other *swaras/ shrutis* can be generated using these two core principles. Therefore, these consonances- 'arithmetic mean' and the 'harmonic mean', may be termed the laws of musical inference. The actual implementation

of these ratios is explained as follows. In simple terms, if there are two *swaras* Sa and the higher Sa then from these two *swaras* if we go on applying the ratios of 'arithmetic mean' and the 'harmonic mean' then we can generate all the *swaras* such as Pa, Ma, Ga, KGa, Re and KRe, in the same order, that are required for generating all the remaining *swaras* of the *Saptaka* or an octave.

The ratio of 'arithmetic mean' is represented by AM = (X1 + X2) / 2 and the ratio of 'harmonic means' is represented as HM = 2* X1* X 2/ (X1+ X 2).

If we assume the values of *swara* Sa as 240 Hz. and the value of higher Sa as 480 Hz. then by applying these two ratios, we get the values of *swara* Pa and *swara* Ma respectively. So, if X1 is Sa and X2 is higher Sa then

AM = 240+480/ 2 = 360 which is the value of *swara* Pa and

HM= 2*240*480/ (240+480) = 320 which is the value of Ma *swara*.

Interestingly, if we assign X1 = 320 and X2 = 360 then their arithmetic mean is the *swara Teevra* Ma or Mat with the value 340. If we apply the harmonic mean then we will get another value of 337.5 which is very close to the previous value. AM = 320+360/ 2 = 340 which is taken as the value of the *swara* Mat in this harmonic *swara* scale.

There exists a generative hierarchy of these *swaras* and related laws of musical inference. For instance, if we apply ratios of 'arithmetic mean' and 'harmonic mean' on the *swara* Sa and *swara* Pa then we get the values of *swara* Ga and *swara Komal* Ga as follows.

AM = 240+360/ 2 = 300 which is the value of *swara* Ga and

HM= 2*240*360/ (240+360) = 288 which is the value of *Komal* Ga *swara*.

Thus, we can prove the role of the laws of 'arithmetic mean' and the 'harmonic mean' in GTIM. Similarly, from the *swara* Sa and *swara* Ga, we get the *swara* value for Re by applying the ratio of 'arithmetic mean' as follows.

AM = 240+300/ 2 = 270 which is the value of *swara* Re and then if we apply the same ratio to Sa and Re then we get the value of *Komal* Re as shown below.

AM = 240+270/ 2 = 255 which is the value of *swara* Komal Re. In the last two instances, we did not apply the ratios of 'harmonic mean' because the resultant values are very close to the above values. The precedence is given to the rule of 'arithmetic mean' in both cases.

If we apply the same ratio to *swara* Sa and *swara Komal* Re then we get *Ati-Komal* Re for a value of 247.5 but it is not required as the 12 *swara* scale does not have *Ati- Komal* Re. However, it can be included while comparing it with the Bharata Muni's scale. Even Bharata Muni's scale has *swara Ati-Komal* Re with the same value.

Similarly, a value of 280 for *Ati-Komal* Ga can be derived from Sa and Ma *swaras*.

Till now *swaras* of the *Poorvanga* (first half) of a *Saptaka* are established. For establishing the *swaras* of the *Uttaranga* (later half) of a *Saptaka*, we need to apply the ratio of 'arithmetic mean' to each of these *swaras* because the *swaras* of the *Uttaranga* can be derived from the *Poorvanga swaras* by applying the *Shadja-Panchama Bhava*.

If we apply the 'arithmetic mean' ratio to Ga of 300 Hz. Then we should get the value of *Nishad swara*. If X1 = 300 then 2*X1 would be 600 so we get the value of *Nishad* as follows.

AM = 300+600/ 2 = 450 which is the value of *swara Nishad* and the same way if we apply the ratio of 'harmonic mean' to Ga then we get the value for *Dhaivata* *swara* as shown below.

HM= 2*300*600/ (300+600) = 400 which is the value of Dha swara.

From the *Komal* Ga of 288 Hz. We get the *Komal Nishad* by applying the ratio of 'arithmetic mean' as follows and we get *Komal Dhaivata* by applying the ration of 'harmonic mean' to *Komal Gandhara* as follows.

AM = 288+576/ 2 = 432 which is the value of *swara Komal Nishad*

HM= 2*288*576/ (288+576) = 384 which is the value of *Komal Dhaivata swara*.

In the same manner, if we apply the ratio of 'arithmetic mean' to the *swara* Re having a frequency value of 270 Hz. Then we get another value for the *swara Dhaivata* as follows.

AM = 270+540/ 2 = 405 which is the value of *swara Dhaivata* and by applying the ratio of 'harmonic mean' we get the value of *swara* Pa which is repetition because we already have the *swara* Pa.

HM= 2*270*540/ (270+540) = 360 which is the value of Pa *swara* which is a repetition.

From the *swara Komal* Re of 255 Hz. By the ratio of 'arithmetic mean' we get *swara Komal Dhaivata* with the value 382.5 as follows and the *swara* Mat by the ratio of 'harmonic mean' as follows. Here again, the *swara* Mat is repeated and therefore, it is redundant.

AM = 255+510/ 2 = 382.5 which is the value of *swara Komal Dhaivata*

HM= 2*255*510/ (255+510) = 340 which is the value of Mat *swara* that is *Teevra* Ma which is a repetition.

In the above formulations, we can see that we derived two different values for the *swaras Dhaivata* (405 Hz. And 400 Hz.) and *Komal Dhaivata* (384 Hz. And 382.5 Hz). For the audience, these values are not distinguishable and therefore they cannot be considered as separate values.

At the end of this process, we arrive at the scale of 12 *swaras* that look as follows. Harmonic *Swaras* = {240 (Sa), 255 (KRe), 270 (Re), 288 (KGa), 300 (Ga), 320 (Ma), 340 (Mat), 360 (Pa), 382.5 or 384 (KDha), 400 or 405 (Dha), 432 (KNi), 450 (Ni), 480 (Higher Sa)}.

This scale may be termed HS-12 (Harmonic *Swaras*- 12) because it is based on the ratios of 'Arithmetic Mean' and 'Harmonic Mean'. This is not a hypothetical mathematical formulation because the various ratios mentioned above are based on the actual harmonics generated when a string is plucked. Also, all the values mentioned in this scale are part of the JI-12 scale. All these swaras are aesthetically pleasing ratios and therefore the *swaras* of this harmonic *swara* scale are also aesthetically pleasing. The phenomenon of generative hierarchy is valid in the case of this scale. It indicates a deeper level of consistency among the fields of physics, mathematics and music.

The following table gives a comparative view of the four scales. The Just Intonation JI-12 scale, ET-12 scale, and Bharata Muni ET-22 were already discussed in the previous chapter. The Harmonic *Swaras* HS-12 scale that is just developed is significant from a musical point of view since it is based on the principles of consonance. If we compare values of 12 *swaras* across these four scales then we realize that the differences are very minimal. In the context of a musical performance which is a very dynamic activity using *Aalaps, Taans and Gamakas*, such a minimal difference in *swara* values is not noticed by the common audience and to some extent even by the trained audience. Probably that is the reason ET- 12 scale, though deviating from the harmonic frequency values in a strict sense, has become so popular in India as well as in the West. The same is the case with Bharata Muni's ET-22 scale which has been the standard till the 12th century AD though it also deviated from the mathematical harmonic values.

Swaras	**JI-12 Scale**	**ET-12 Scale**	**Harmonic *Swaras*- 12**	**Bharata Muni's *Swara*-Values**
Sa	240	240	240	240
KRe	250, **256**, 266.66	254.27	255	255.6
Re	270	269.39	270	272.23
KGa	288	285.41	288	289.94
Ga	300	302.38	300	299.22
Ma	320	320.36	320	318.68
Mat	337.5, **341.333**	339.41	340	339.41
Pa	360	359.59	360	361.48
KDha	384	380.98	382.5, **384**	384.99
Dha	400	403.63	**400**, 405	410.03
KNi	420, 426.66, **432**	427.63	432	436.7
Ni	450	453.06	450	450.68
HSa	480	480	480	480

This chapter begins with a discussion of the principles of consonance and dissonance. Consonances are responsible for the beauty of music. The chapter elaborates on the theoretical principles behind the phenomenon of consonances and dissonances and illustrates them with graphical representations. Indian music recognizes consonances such as *Shadja-Panchama Bhava, Shadja-Madhyama Bhava, Shadja-Gandhara Bhava* and *Shadja-Rishabha Bhava*. GTIM argues that Indian music is based on these principles of consonances and thus this chapter is very important. At the end of this chapter, a consonance-based scale called the Harmonic *Swara* scale (HS-12) is developed. It is based on the ratios of the 'Arithmetic Mean' and the 'Harmonic Mean' which represent two core consonances. The GTIM accepts all four scales, viz. ET-12, JI-12, Bharata Muni's ET-22 scales discussed in the previous chapter and the HS-12 scale as valid scales. The GTIM-based Artificially Intelligent systems called *AIRaga* developed by the author have a provision for using all four tuning systems. The next chapter also discusses the necessary integration of the HS-12 scale with Bharata Muni's ET-22 scale.

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CHAPTER 7

Setting the Harmonic Context

Introduction

As it is discussed in the previous chapters that during Bharata Muni's times, there were sophisticated methods to establish *swaras, shrutis* and *Saptaka*. Ancient literature suggests that a *Veena* and a *Venu* (a flute) were the two widely used musical instruments. The description of *swaras* and *shrutis* is therefore always in the context of these two instruments. *Naradiya Shiksha*, *Natyashastra* and *Sangita Ratnakar* provide all the foundational knowledge about *swaras, shrutis* and *Saptaka*. Though there is a mention of an instrument called *Tambura* in ancient literature and other sources, which is also known as *Tanapura* nowadays, we do not find any reference to its special usage as a drone instrument in music. Probably later on during medieval times, *Tanapura* became an important drone instrument in Indian music. This impacted Indian music to a great extent. Therefore, it becomes inevitable to understand the contribution of *Tanapura* in Indian music and how its role in musical performance is critical.

Tanapura Tuning

Tanapura plays a seminal role in providing a harmonic context in musical performance. In the previous chapter while discussing the concept of 'implied harmony' we discussed the acoustics of *Tanapura* and its impact on the generation of consonances. During Bharata Muni's times, there was a *Granma* system of *Shadja Grama* and *Madhyama Grama*. In some ways, *Grama* refers to a tuning system but we do not have any conclusive evidence to prove that. The *Grama* system is not in practice any more. Also, we do not have evidence of *Tanapuras* in those days. Keeping aside that factor we can consider that contemporary tuning of *Tanapura* may be treated as *Shadja Grama*. As per prevalent practices, *Tanapura* is tuned in two ways. The most popular practice is based on the principle of *Shadja-Panchama Bhava*. Typically, *Tanapura* has four strings. The middle two strings are tuned in the *Shadja swara* of the middle octave. The first string is tuned to the *Shadja swara* of the lower octave or the '*Kharja*' *Shadja swara*. The

the fourth string is tuned to the *Panchama swara* of the lower octave or the '*Kharja*' *Panchama*. This is the popular, standard way of tunning the *Tanapura*. This tunning is popular because it is suitable for most of the *Ragas*. There are two other alternate ways of tuning the *Tanapura*. The second type of tuning is preferred when *Panchama* is a *Varjya swara* (omitted) in the *Raga*. As it is mentioned earlier, the fourth string of the first type of tuning is tuned to lower *Panchama*. Most of the *Ragas* have *Panchama* as an important *swara* so it suits most of the *Ragas*. However, if *Panchama swara* is eliminated from the *Raga* then naturally, *Madhyama* becomes the important *swara*. But then lower *Panchama* of the first type of tuning makes its presence felt and spoils the mood of the *Raga*. To avoid such a disturbance if *Panchama* is a *Varjya swara* in the *Raga* then the fourth string of the *Tanapura* is tuned to the lower *Madhyama* or '*Kharja*' *Madhyama swara*. This is also a popular tuning of *Tanapura*. There exists one more type of tuning which is not so popular because generally it is not used in musical performances. Mostly it is used in practice or '*Riyaz*'. In this case, the fourth string of the *Tanapura* is tuned to the lower *Shuddha Nishad swara* or the '*Kharja*' *Nishad*. Sometimes instead of *Shuddha Nishad*, some practitioners prefer '*Kharja*' *Komal Nishad swara*. The third type of tuning has a peculiar flavour as due to the presence of *Nishad swara* in the *Tanapura* tuning, the *Gandhara swara* in the *Raga* gets some kind of harmonic support. The author of this book has experimented with a few more variations of tuning on '*Bharat Veena*'. Bharata Muni's *Saptaka* was different from contemporary *Saptaka*. There 'Bharata Muni's *Gandhara*' is an important *swara* in that *Saptaka*. So, the fourth string of the *Tanapura* can be tuned into Bharata Muni's *Gandhara* of the lower octave. Alternatively, it can be tuned to Bharata Muni's lower *Nishad swara*. In both cases, the mood that is created by tuning is quite different. This *Tanapura* tuning suits to overall *Bharata Muni Veen* tuning. Probably, this tuning can be termed as *Gandhara Grama* tuning but we do not have any historical or literary evidence for the same.

Tanapura Harmonics

It is often claimed that the *Tanapura* provides a harmonic context to the musical performance. It is very interesting to understand this phenomenon. As it is earlier mentioned that there are four strings to the *Tanapura*. The middle two strings are tuned to the *Shadja swara* of the middle octave. The moment we start plucking the *Tanapura* and keep it plucking, gradually, the *Shadja swara* becomes the most dominant and prevalent *swara* in the atmosphere/ musical ambience. *Shadja* is the natural tonic of the *Saptaka*. So, in a way, from a psycho-acoustical perspective, a *Saptaka* with *Shadja* as a tonic is established. Simultaneously, strings of the lower *Shadja* and the lower *Panchama* are also being plucked. So, there is also a presence of lower *Shadja* and the lower *Panchama* in the musical atmosphere. The phenomenon is interesting and worth probing further from a scientific point of view. The close scrutiny of this phenomenon reveals that it is not only an experiential phenomenon or a psychological phenomenon but it is also a physical phenomenon. It is so because when these strings are constantly plucked, along with the main frequencies of lower *Shadja* and lower *Panchama swaras*, upper partials and harmonics of all these *swaras* are also generated and they are present in the atmosphere. Let us understand this phenomenon briefly. When a string is plucked it generates natural frequencies. It is never a single frequency. Depending upon the material qualities of *Tanapura* and the string, various harmonics are generated. Upper partial tones are also generated due to the quality of the material of the string that contributes to the timbre of the sound. Our experience of the plucked sound is a cumulative effect of the main frequency and its harmonics along with the upper partials. For instance, let us assume that we have a *Tanapura* with four strings tuned in as explained earlier. Let us also assume that the frequency of *Shadja* is 240 Hertz. When we pluck the strings of *Shadja swara*, a frequency of 240 Hertz is generated along with its harmonics. Harmonics are the multiples of the original frequency. So, harmonics will be generated along with the original frequency of 240 Hertz as follows.

240, 480, 720, 960, 1200, 1440, 1680 ...

We listen to these harmonics along with the original frequency. The volume and intensity of the harmonics and partial tones are in gradually decreasing order. So, we here 240 Hertz frequency loudly and clearly while other harmonics are heard in decreasing volume. Our experience of sound is thus a cumulative experience of all the harmonics and upper partials generated by a plucked string. The *Tanapura* also has the string for lower *Shadja* and that is also being plucked continuously. In this case, the frequency of lower *Shadja* is 120 Hertz which is half of the original *Shadja swara*. Now harmonics of lower *Shadja* are also generated when we pluck the strings. The harmonics of lower *Shadja* will be as follows.

120, 240, **360**, 480, **600**, 720, 840 ...

We listen to these harmonics as well along with the previously mentioned harmonics of the main *Shadja swara*. All these sound frequencies are spread in the environment which is musically possessed. We process these frequencies and ‘infer’ the *swaras* from them. The Audience is an active listener consciously and unconsciously comparing, relating and processing these frequencies and trying to make sense of them. When two strings of *Shadja swara* are plucked the harmonics that are produced are the higher and higher instances of the *Shadja swara* itself. If the *Shadja* is 240 Hertz then 480 Hertz is the frequency of higher *Shadja* and so on. Two middle strings of a *Tanapura* are constantly generating instances of *Shadja swaras* for higher and higher *Saptakas*. With this context, if we compare the harmonics generated by the lower *Shadja swara* we realize that certain specific harmonics can be interpreted as specific *swara* frequencies of a *Saptaka*. For instance, the third harmonic of the lower *Shadja* is 360 Hertz, which in comparison with the 240 Hertz of the middle *Shadja* is interpreted as a *Panchama swara*. Similarly, the fifth harmonics of lower *Shadja* with the value of 600 Hertz in comparison with the 480 Hertz which is a second harmonics of middle *Shadja* is interpreted as the *Gandhara swara* of that *Saptaka*. Traditionally this *Gandhara* is known as '*Swayambhu*' *Gandhara* [Pandya, P. K., 2005]. This means that by plucking two strings of middle *Shadja* and one string of lower *Shadja swara* we can infer the presence of at least the *Panchama swara* and the *Gandhara swara*. This happens due to the aural inferencing processes. When we pluck the fourth string of the *Tanapura* dedicated to the lower *Panchama*, the following harmonics are generated. The frequency of lower *Pancham*a is 180 Hertz. So, the harmonics will be as follow.

180, 360, **540**, 720, **900**, 1080, 1260 ...

When we hear these harmonics in the context of other harmonics generated by the middle *Shadja* and the lower *Shadja swara*, we interpret the third harmonics of this *Panchama* string as a '*Swayambhu*' *Rishabha swara*. This is interpreted as *Rishabha* with the 480 Hertz harmonics generated by the middle *Shadja*. Apart from the fifth harmonics of 900 Hertz of the *Panchama* string is interpreted as '*Swayambhu*' *Nishad swara* in comparison with the 720 Hertz harmonics generated by the middle *Shadja*. Thus, it is fascinating to understand the dynamics of relationships between and among various harmonics generated by the four strings of a *Tanapura*.

The above discussion is limited to the *Tanapura* where the fourth string is tuned to the lower *Panchama swara*. But there is another method of tuning a *Tanapura* by tuning the fourth string into lower *Madhyama swara*. For this tuning, the lower *Madhyama* string will generate the following harmonics. The value of lower *Madhyama* is 160 Hertz.

160, 320, 480, 640, 800, 960, 1120 ...

Here it is worth mentioning that certain harmonics such as the harmonics of value 800 will be interpreted as '*Swayambhu*' *Dhaivata* and the harmonics with value 1120 will be interpreted as '*Swayambhu*' *Ati-Komal Gandhar* or which is known as Bharata Muni's *Gandhara*.

Tanapura Harmonics and Bharata Muni's *Shrutis*

We tried to understand why and how the presence of '*Swayambhu*' Gandhara, '*Swayambhu*' *Rishabha* and '*Swayambhu*' *Nishad* are experienced when strings of a *Tanapura* are plucked. We also saw why the presence of '*Swayambhu*' *Dhaivata* and Bharata Muni's *Gandhara* is also felt. It is known that when a string is plucked, the human ear can notice the first five harmonics easily and some people can notice their presence up to the first seven to ten harmonics. In the case of a *Tanapura,* it can be noticed that many of the harmonics are repeatedly generated, for instance, harmonics of value 480, 360, and 720 are generated repeatedly when we are just taking into account the first seven harmonics of four strings. The repetition of specific harmonics from different source strings results in the cumulative added volume of such harmonics. The above discussion is restricted to the first seven harmonics of *Tanapura* strings however, as we know harmonics are generated endlessly though their volume and intensity reduce gradually. Considering the cumulative addition of repeatedly generated harmonics it is assumed that up to 18 to 20 harmonics of each string are worth analyzing and understanding what types of '*Swayambhu*' *swaras* are generated due to harmonic dynamics. For the discussion and analysis, it is assumed that the *Tanapura* has five strings where the fourth string is for lower *Panchama* and the fifth string is for lower *Madhyama swaras* respectively.

Sa, Pa, Ma harmonics for a *Tanapura* with 18 cycles per *swara* (18 cycles of Sa, 18 cycles of Pa and 18 cycles of Ma = 54) are as follows. Let us call them 'Harmonic *Shrutis'*.

240,247.5,255,260,270,280,285,292.5,300,315,320,330,337.5,340,360,380,382.5,390,400,405,420,427.5, 440,450,480.

The total number of harmonic *shrutis* including the *Tara Shadja shruti* is: 25 Number of occurrences of each harmonic *shrutis* are shown as follows. The first number in each square bracket is the harmonic *shruti* while the second number suggests the number of occurrences of that harmonic *shruti* in the first 18 harmonics.

[240,2], [247.5,1], [255,1], [260,1], [270,5], [280,2], [285,1], [292.5,1], [300,3],

[315,2], [320,5], [330,1], [337.5,1], [340,1], [360,10], [380,1], [382.5,1], [390,1],

[400,2], [405,2], [420,2], [427.5,1], [440,1], [450,3], [480,6].

For reference and comparison, the following is the list of Bharata Muni's twenty-two *shrutis* based on the equal temperament paradigm from Bharata's *Natyashastra*. Names of the *swaras/ shrutis* are indicated in brackets.

Bharata Muni's 22 *Shrutis* are as Follows:

[240 (*Shadja*), 247.682 (*Chyuta Komal Rishabha*), 255.6 (*Komal Rishabha*), 263.79 (Bharata Muni's *Rishabha*), 272.235 (*Chatushruti Rishabha*), 280.948 (Bharata Muni's *Gandhara*), 289.941(*Sadharan Gandhar*), 299.222 (*Antar Gandhara*),308.799 (*Chyuta Madhyama*), 318.684 (*Madhyama*), 328.884 (*Chyuta Teevra Madhyama*), 339.411 (*Teevra Madhyama*), 350.275 (*Chyuta Panchama*), 361.487 (*Panchama*), 373.057 (*Chyuta Komal Dhaivata*), 384.998 (*Komal Dhaivata*), 397.322 (Bharata Muni's *Dhaivata*), 410.039 (*Chatuh Shruti Dhaivata*), 423.164 (Bharata Muni's *Nishada*), 436.708 (*Kaishiki Nishada*), 450.687 (*Kakali Nishada*), 465.113 (*Chyuta Shadja*), 480 (*Taara Shadja*)] If we compare the harmonic *shrutis* with the Bharata Muni's equal temperament set of 22 *shrutis* we can see that many of the harmonic *shrutis* are very close to Bharata Muni's respective *shrutis*. So, taking into account the context of musical performance and the way *swaras* and *shrutis* are rendered, such a minute difference does not matter. Also, it is very difficult for a musician to sustain a particular *swara* frequency for a longer duration- even for 30 seconds. When a *swara* is rendered, it always oscillates around the desired frequency. It never stays on that particular frequency for long. Similarly, on *Tanapura* when a string is plucked it does not vibrate on one single frequency. It oscillates. This is known as the '*Javari*' effect. When a string is stretched on the bridge of the *Tanapura*, a cotton thread is placed between the string and the bridge. This thread is called '*Javari*'. When a string is plucked it oscillates because of the padding of *Javari* cotton and a typical *Tanapura* sound is produced. This sound is never a single frequency. There are micro-level dynamic variations in the frequencies produced by the string. The is a well-established phenomenon.

Bharata Muni's equal temperament twenty-two *shruti* paradigm is important because it is the all-encompassing and accommodative paradigm for providing aural and harmonic foundations to Indian music. As it is discussed earlier harmonics have a seminal role in creating the aural harmonic context for a musical performance. The Bharata Muni's *shrutis* somehow are placed on the frequencies positions which can be mapped on at least the first thirty-two harmonics generated by *Shadja*, *Panchama* and/ or *Madhyama swaras* that are tuned on the *Tanapura*. It is evident from the following analysis. Assuming the value of *Shadja swara* as 240 Hertz on *Tanapura*, and values of *Panchama* and *Shadja swaras* as 360 Hertz and 320 Hertz respectively, when we keep plucking *Tanapura* strings, a stream of harmonics is generated. Due to the repetition of certain harmonic values, their volume becomes stronger and a drone effect is generated. As discussed, the initial five to seven harmonics of each string are naturally strong. But the higher harmonics lose their volume and intensity gradually and perish in the environment. Still up to eighteen to twenty-two harmonics of each string are strong enough and trained ears can sense their presence. Trained musicians can tune the *Tanapura* without taking support from tuners or Harmonium. Consciously or unconsciously, the audience is also aware of the presence of such harmonics. The following *shruti* values in bold letters can be very closely mapped on Bharata Muni's *shrutis*, taking into account the *Javari* effect. In another sense, many of the Bharata Muni's *shruti* values fall on the harmonic values if we take into account eighteen harmonics of each string of the *Tanapura*. The author has developed software to simulate harmonics and calculate the values of *Tanapura* frequencies. The following analysis is based on these simulations.

Sa, Pa, Ma harmonics for a *Tanapura* with 18 harmonics of each string are as follows.

240, 247.5, 255, 260, **270**, **280**, 285, **292.5**, **300**, 315, **320**, **330**, 337.5, **340**, **360**, 380, **382.5**, 390, **400**, 405, **420**, 427.5, 440, **450**, 480.

Bharata Muni 22 *shrutis* are as Follows:

240, 247.682, 255.6, 263.79, **272.235, 280.948**, **289.941, 299.222**, 308.799, **318.684, 328.884**, **339.411**, 350.275, **361.487**, 373.057, **384.998**, **397.322**, 410.039, **423.164**, 436.708, **450.687**, 465.113, 480

There are roughly at least fifteen *shrutis* of Bharata Muni's paradigm that can be mapped on the first eighteen harmonics of *Tanapura* as we can see in the above comparison. If we consider about thirty-two harmonics of *Tanapura* then we can see that almost all twenty *shrutis* from Baharat Muni's paradigm can be mapped on *Tanapura* harmonics. It is shown as follows.

Sa, Pa, Ma Harmonics-32 harmonics of each string of the *Tanapura are* as follows.

240, 247.5, 250, **255**, 258.75, 260, **270**, **280, 281.25**, 285, **290, 292.5**, **300**, 303.75, **310**, 315, **320**, 326.25, **330**, 337.5, **340**, 345, **348.75**, **360**, **371.25, 375**, 380, **382.5**, 390, **400**, 405, **420**, 427.5, **435**, 440, **450**, 460, **465**, 472.5, **480**

If we try to map the first 18 to 20 harmonics then again a smaller number of harmonics will be mapped and if we map 30 to 32 *Tanapura* harmonics then a greater number of harmonics are mapped on Bharata Muni's *shrutis*. This suggests that the Bharata Muni's paradigm of twenty-two *shrutis* appears to be a broader framework that provides a foundational structure to musical performance.

Bharata Muni's paradigm is not only significant from the *Tanapura* harmonics point of view but it is significant from many other factors. We need to understand musical performance at multiple levels. As we are discussing *Tanapura* harmonics this is the first important level. The *Tanapura* generates a psycho-acoustically significant harmonic ambience base for the musical performance. Harmonics are generated that are physically present in the ambience. However, the audience is actively listening to these harmonics and interpreting and inferring and making musical sense out of it. Since some of the harmonics are mapped on Bharata Muni's *shrutis* as discussed above, it becomes easy to make sense of it. Bharata Muni's paradigm is the most accommodative and comprehensive framework that provides foundations for other levels as well. Apart from *Tanapura* harmonics, there exists another level that is called a 'scaler' level. The most popular contemporary scale is the equal-tempered scale of 12 *swaras* which is called ET-12. There is another scale called 'just-intonation' scale or a JI-12 scale. Bharata Muni's scale is called the ET-22 scale. The scale or the tuning system decides the musical notes that are used in the rendering. *Swaras* of a *Mela* or a *Thaata* are chosen from the particular scale as mentioned. The scaler structure or a tuning system is very important and puts some constraints on musical performance in terms of several *swaras*. *Swaras* of a Raga are chosen from a particular scale- a *Thaata* or a *Mela*. Thus, the scaler level is the level where in North Indian music, '*Thaata*' of a *Raga* and *Mela* of a *Raga* in Carnatic music puts constraints on the performance. The *Mela* system is supposed to be strictly based on Bharata Muni's paradigm so the *swaras* of *Melas* are strictly mapped on Bharata Muni's *shrutis* (though there is a need for empirical research in this regard).

The third level is a very important level of analysis which is the level of *Raga*-specific *swaras* that are rendered during the performance. When a *Raga* is rendered, the most important *swara* is the *Vadi swara*. Along with a *Vadi swara*, there are *Raga*-specific *swaras* like *Samvadi*, *Anuvadi*, and *Anu-Anuvadi swaras* that are also rendered. Although all the *Raga*-specific *swaras* are taken from the scaler structure, musicians have the experience that they do not strictly adhere to fixed scaler values of frequencies of that specific scale. Many a time they deviate from the *scaler* values. Interestingly, they follow a different logic called 'Aural' Logic. *Vadi swara* of the *Raga* has an affinity for certain *swaras* that follow laws of consonance. These are *Shadja-Panchama Bhava, Shadja-Madhyam Bhava, Shadja-Gandhar Bhava, Shadja-Komal Gandhar Bhava, Shadja-Rishabha Bhava and Shadja-Komal Rishabha Bhava*. So, when the *Vadi swara* of a *Raga* is rendered again and again for creating the mood of the *Raga*, it necessitates the presence of relevant *swaras* generated by the laws of consonances. These *swaras* and their frequencies might deviate from the fixed scaler frequencies but performers use them because these *swaras* bring in unique musical quality that is specific to that *Raga*. '*Raganess*' of a *Raga* thus depends upon such special *swara* frequencies. For instance, the *Komal* Re of *Raga Ahir Bhairava* will be different from the *Komal* Re of *Raga Marava* or *Raga Poorvi* for that matter. Such specifications of *swara* and *shruti* applications are well known and performers render such *Raga*-specific *swaras* and *shrutis* to bring in the '*Raganess*' of the particular *Raga*.

Tanapura Harmonics and "*Shruti Megha*"

Interestingly, such *Raga*-specific unique frequencies can be closely mapped on Bharata Muni's *shrutis*. The popular ET-12 scale cannot capture such specificities. Bharata Muni's paradigm becomes very important in this sense. The following examples will illustrate this phenomenon. This discussion is very important to understand the real crux of Indian music. Let us assume that *Tanapura* is constantly playing generating a constant flow of harmonics. Thus, the harmonic context is built. When a performer renders the *Vadi swara* again and again, certain harmonics will be augmented and their presence will be experienced. It may be called the 'Aural *Swara-Mandala'* of harmonics. This will be more specific to that particular *Vadi swara*. As already discussed, when a *swara* is rendered, all the harmonics are generated so when a *Vadi swara* is rendered repeatedly all the harmonics get generated and become stronger and stronger. Therefore, for every *Raga,* there exists a *Vadi*-specific Aural *Swara-Mandala* apart from the generic Aural *Swara-Mandala* generated by the *Tanapura*. The following discussion tries to show that certain *Vadi*-specific harmonics bring in the '*Raganess*' to the *Raga* rendering. The beauty of Bharata Muni's ET-22 paradigm is that it comprehensively accommodates all such *Vadi*-specific harmonics. Equal temperament twenty-two *shrutis* are positioned in such a way that all such *Vadi*-specific harmonic nuances are captured. The computational analysis suggests that there are at least 90 frequency values that are generated by various *Vadi swaras* of different *Ragas* and all of them fall within close vicinity range of Bharata Muni's twenty-two *shrutis*. This set of frequency values is named a '*Shruti Megha*' (cloud of microtones) here. These 90 *Shruti-Megha* frequency values are calculated considering the frequency value of Sa as 240 Hertz. as follows. These values may be termed 'nano *shruti*' values.

Shruti Megha:

[240,243,247.5,250,252,253.13,255,256,259.2,262.97,263.79,266.67,270,270.94,272,278.44,280,281.25,283.33,286.88,288,289.94,295.83,297,297.5,299.22,300,303.75,304.81,306,309.38,313.25,315,318.75,320,322.74,324,328.88,330,334.69,336,337.5,339.41,340,341.73,344.25,345.6,350.01,354.38,358.6,360,361.25,364.5,371.25,373.33,375,379.69,382.5,384,385,394.45,396,397.32,400,405,406.41,408,410.04,412.5,417.66,420,423.16,425,426.67,430.31,432,436.71,446.25,448,450,450.69,453.34,455.63,459,460.8,464.07,465.11,466.67,472.5,478.13,480]

The number of nano-*shrutis* in the *Shruti Megha* including the main *shrutis* as well as the higher *Shadja* is 91. It means that although there are 22 *shrutis* as reference microtones in the traditional scale of Bharata Muni, the harmonic analysis suggests that there are 90 microtones that are eventually used in Indian music. Most of these microtones are *Vadi*-specific harmonics on the basic 22 reference *shrutis* mentioned by Bharata Muni. *Vadi*-specific 'Aural *Swara-Mandalas'* are given below so that it becomes clear how each *Vadi swara* is contributing to these 90 values. Eventually one realizes that all these 90 values fall in close vicinity of respective *shrutis* of Bharata Muni's scale. It is recommended that the readers should read the author's monograph titled 'The Doctrine of *Shrutis* in Indian Music' for more insights regarding the concept of '*Shruti Megha'*. The author has proposed an equal temperament *Shruti Megha* of 110 *shrutis* in the monograph and to be precise the above-mentioned harmonic 90 *shrutis* fall within close vicinity of them. [Vidwans, V. V., 2016].

Bharata Muni's 22 *shrutis* are as Follows:

[240, 247.682, 255.6, 263.79, 272.235, 280.948, 289.941, 299.222, 308.799, 318.684, 328.884, 339.411, 350.275, 361.487, 373.057, 384.998, 397.322, 410.039, 423.164, 436.708, 450.687, 465.113, 480]

Tanapura frequencies up to 18 harmonics for the *Shadja swara* of 240 Hz. are as follows:

[240, 247.5, 255, 260, 270, 280, 285, 292.5, 300, 315, 320, 330, 337.5, 340, 360, 380, 382.5, 390, 400, 405, 420, 427.5, 440, 450, 480].

If *Komal Rishabha* is a *Vadi* of the *Raga*:

Aural *Swara-Mandal* for *Komal Rishabha* with frequency of 255 Hertz is as Follows:
[240, 255, 262.97, 270.94, 286.88, 297.5, 306, 318.75, 340, 360, 361.25, 382.5, 394.45, 406.41, 430.32, 446.25, 459, 478.13, 480 [306, 459, 478.13].

If *Rishabha* is a *Vadi* of the *Raga*:

Aural *Swara-Mandal* for *Rishabha* with frequency of 270 Hertz is as Follows:
[240, 243, 253.13, 270, 278.45, 286.88, 303.75, 315, 324, 337.5, 360, 381.18, 382.5, 405, 417.66, 430.32, 455.63, 472.5, 480] [243,].

If *Komal Gandhara* is a *Vadi* of the *Raga*:

Aural *Swara-Mandal* for *Komal Gandhar* with frequency of 288 Hertz is as Follows:
[240, 243, 252, 259.2, 270, 288, 297, 306, 324, 336, 345.6, 360, 384, 406.59, 408, 432, 445.5, 459, 480].

If *Gandhara* is a *Vadi* of the *Raga*:

Aural *Swara-Mandal* for *Gandhara Swara* with frequency of 300 Hertz is as Follows:
[240, 253.125, 262.5, 270, 281.25, 300, 309.375, 318.75, 337.5, 350, 360, 375, 400, 423.53, 425, 450, 464.06, 478.13, 480].

If *Madhyama* is a *Vadi* of the *Raga*:

Aural *Swara-Mandal* for *Madhyama* with frequency of 320 Hertz is as Follows:
[240, 247.5, 255, 270, 280, 288, 300, 320, 330, 340, 360, 373.33, 384, 400, 426.67, 451.77, 453.34, 480].

If *Panchama* is a *Vadi* of the *Raga*:

Aural *Swara-Mandal* for *Panchama* with frequency of 360 Hertz is as Follows:
[240, 254.12, 255, 270, 278.44, 286.875, 303.75, 315, 324, 337.5, 360, 371.25, 382.5, 405, 420, 432, 450, 480, 480].

If *Komal Dhaivata* is a *Vadi* of the *Raga*:

Aural *Swara-Mandal* for *Komal Dhaivata* with frequency of 382.5 Hertz is as Follows:
[240, 255, 270, 270.94, 286.875, 295.835, 304.81, 322.735, 334.69, 344.25, 358.6, 382.5, 394.45, 406.41, 430.31, 446.25, 459, 478.13, 480].

If *Dhaivata* is a *Vadi* of the *Raga*:

Aural *Swara-Mandal* for *Dhaivata* with frequency of 405 Hertz is as Follows:
[240, 243, 253.125, 270, 285.88, 286.875, 303.75, 313.245, 322.735, 341.725, 354.375, 364.5, 379.69, 405, 417.66, 430.31, 455.63, 472.5, 480].

If *Bhinna* (different) *Dhaivat*a is a *Vadi* of the *Raga*:

Aural *Swara-Mandal* for *Bhinna Dhaivata* with frequency of 400 Hertz are as Follows:
[240, 250, 266.665, 282.35, 283.335, 300, 309.375, 318.75, 337.5, 350.005, 360, 375, 400, 412.5, 425, 450, 466.67, 480, 480].

If Sa is a *Vadi* of the *Raga*:

Aural *Swara-Mandal* for *Shadja* with frequency of 240 Hertz is as Follows:
[240, 247.5, 255, 270, 280, 288, 300, 320, 338.82, 340, 360, 371.25, 382.5, 405, 420, 432, 450, 480].

The above-mentioned list of 90 frequencies is extracted from these 'Aural-*Swara-Mandalas*'. Often a question is asked that how only twenty-two *shrutis* are sufficient to render all the *Ragas*. The question is valid and all the performers agree that while rendering a *Raga* one does not stick to the fixed scale of 12 *swaras* or Bharata Muni's 22 *shrutis*. Many in-between frequencies are rendered and therefore, many music researchers argue that *shrutis* are infinite. Even this issue is as old as Matanga Muni's *Brihaddeshi* where this question is raised and according to Kohala, some believe in 22 *shrutis* while some other scholars differentiate them into 66 kinds and many others describe the infinity of *shrutis*. [Sharma, Prem Lata, 1992, Vol. 1, pp. 8-15] The above analysis tries to throw light on this issue. As per the discussion so far it is becoming clear that Bharata Muni's paradigm of twenty-two *shruti* is a broader framework that accommodates many possibilities of microtonal renderings in a *Raga* performance. The key issue is that when a *shruti* is rendered it is a specific *shruti* where it may not be mapped exactly on the Bharata Muni's 22 *shrutis*. Fortunately, the *AIRaga* system can render all 90 microtones as needed. The system has the facility to render Raga in ET-12 scale, Bharata Muni's ET-22 scale and the Harmonic scale. The present discussion is based on the analysis of the results of the testing of a *Raga* rendering on these three scales. The simulation paradigm is very useful in addressing such issues.

Harmonic *Shruti Megha*

As was discussed already that the *Tanapura* provides the harmonic ambience at a very base level. At the scaler level, certain *shrutis/ swaras* are selected that puts certain structural constraints on the *Raga* rendering. This level is important for defining the basic *swaras* of the scale from which *Raga*-specific *swaras* are chosen. At the top level is the *Vadi-Samvadi*-specific set of *swaras* based on the aural harmonic logic that is used in the rendering by the performer. That is the reason *Vadi*-specific 'Aural *Swara-Mandalas'* are presented here. *Swaras/ shrutis* of this set may overlap with the scaler *swaras/ shrutis* but all the *swaras/ shrutis* may not be the same. This is because *Vadi* is the main *swara* of the *Raga* and due to its dominance, aurally significant *swaras* generated by *Shadja- Panchama Bhava* etc. laws become important in the *Raga* that gives a special flavour. Interestingly, in most cases, such *swaras* are not part of the scaler *swaras* but they are part of the Bharata Muni's set of twenty-two *shrutis* with close affinity. Therefore, Bharata Muni's paradigm becomes important in Indian music. The following analysis will make this point clear. The following listings will show which specific frequencies are in the close vicinity of each of the Bharata Muni's *shrutis*. Each of the Bharata Muni's *shruti* is considered a 'Harmonic *Shruti Megha*' made up of the number of harmonic frequencies that are in its close range. The first *shruti* in a square bracket is the main *shruti* of the *Shruti-Megha* of the *Vadi swara* and the *shrutis* in the second square bracket are the member *shrutis* of this *Shruti-Megha*.

Harmonic *Shruti Megha* for each *shruti* of Bharata Muni's ET-22 paradigm is as Follows:

[[[240], [240, 243, 472.5, 478.13, 480]], - Four *shruti* variations for *Shadja Shruti Megha*

[[247.68], [247.5, 250]], -*Ati-Komal Rishabha* or *Chyuta Komal Rishabha Shruti Megha* has two *shruti* variations

[[255.61], [252, 253.13, 255, 256, 259.2]], - *Komal Rishabha Shruti Megha* has five variations

[[263.79], [262.97, 266.67]], -Bharata Muni's *Rishabha Shruti Megha* has only three variations

[[272.24], [270, 270.94, 272]], -The *Chatuh shruti Rishabha* which is contemporary *Shuddha Rishabha Shruti Megha* has three variations.

[[280.95], [278.44, 280, 281.25, 283.33]], -*Ati-Komal Gandhar* which is also known as Bharata Muni's *Gandhar Shruti Megha* has four variations.

[[289.94], [286.88, 288]], -*Komal Gandhar* or *Sadharana Gandhar Shruti Megha* has three variations.

[[299.22], [295.83, 297, 297.5, 300, 303.75]], -*Aantar Gandhar* or *Shuddha Gandhar Shruti Megha* as it is known today has six variations

[[308.8], [304.81, 306, 309.38, 313.25]], -*Chyuta Madhyama Shruti Megha* has four variations

[[318.68], [315, 318.75, 320, 322.74]], -*Madhyama Shruti Megha* has four variations and all of them are quite widely used in music.

[[328.88], [324, 330]], -*Chyuta Teevra Madhyama Shruti Megha* has three variations.

[[339.41], [334.69, 336, 337.5, 340, 341.73, 344.25]], -Interestingly *Teevra Madhyama Shruti Megha* has maximum number of variations. There are seven variations and all are in use.

[[350.28], [345.6, 350.01, 354.38]], -*Chyuta Panchama Shruti Megha* has three variations.

[[361.49], [358.6, 360, 361.25, 364.5]], - *Panchama Shruti Megha* has four variations.

[[373.06], [371.25, 373.33, 375]], *Chyuta Komal Dhaivata Shruti Megha* has three variations.

[[385], [379.69, 382.5, 384]], -*Komal Dhaivata Shruti Megha* has four variations.

[[397.32], [394.45, 396, 400]], - Bharata Muni's *Dhaivata Shruti Megha* has four variations. This *Dhaivata* is considered as *shuddha Dhaivata* in contemporary music. Especially this is the case when *Ga-Dha Vadi-Samvadi* pair is there in the *Raga*.

[[410.04], [405, 406.41, 408, 412.5]], -*Chatushruti Dhaivata* or *Shuddha Dhaivata Shruti Megha* as per the contemporary practice of music has five variations. This is treated as *Shuddha Dhaivata* when *Re-Dha* pair is the *Vadi-Samvadi* for a *Raga*.

[[423.16], [417.66, 420, 425, 426.67]], -Bharata Muni's *Nishada Shruti Megha* which is also an *Ati-Komal Nishad* has five variations.

[[436.71], [430.31, 432]], -*Kaishiki Nishada Shruti Megha* or *Komal Nishad* of contemporary music has three variations

[[450.69], [446.25, 448, 450, 453.34, 455.63]], - *Kakali Nishada Shruti Megha* or the *Shuddha Nishad* of modern music has six variations.

[[465.11], [459, 460.8, 464.07, 466.67, 472.5]]] -*Chyuta Shadja Shruti Megha* has six variations. Probably, in *Bhinna Shadja Ragas* they might be in use but there is a need of empirical data to support this.

The number of Micro-*Shrutis* in the *Shruti Megha* including the main *shrutis* as well as the higher *Shadja* is 91. It means that although there are 22 *shrutis* as reference microtones in the traditional scale, the harmonic analysis suggests that there are 90 microtones that are eventually used in Indian music. Most of these microtones are *Vadi*-specific variations on the basic 22 reference *shrutis* mentioned by Bharata Muni. Apart from *Vadi swara*, other *swaras* such as *Samvadi, Anuvadi* and *Anu-Anuvadis* are also rendered in a *Raga* but the *Vadi swara* is rendered more frequently, or *Vadi* is also a *Nyasa swara* so more time is spent on the *Vadi swara*. *Vadi swara* is also rendered in *Raga*-specific strategic ways such as a *Vakra swara* or with a *Gamaka* or *Meend*. *Vadi swara* has a much more important role in *Raga* rendering. Therefore, the 'Aural *Swara-Mandalas'* of *Vadi swaras* are considered here. Aural *Swara-Mandalas* of *Samvadi* or *Anuvadis* are also generated but their impact is relatively less in the overall *Raga* rendering. The inclusion of such analysis can be highly complex but can be a good topic for research.

This chapter tried to understand the role of the harmonic context provided by a *Tanapura* for musical performance. *Tanapura* harmonics and their mapping on Bharata Muni's ET-22 *shrutis* are critical to understanding various dimensions of Indian music. *Vadi*-specific 'Aural *Swara-Mandalas*', the span of 90 *shrutis* for *Raga* rendering, and the *Shruti-Megha* paradigm provide a good explanation in this regard. The next chapter will position all the discussion so far in a more rigorous logical frame-work.

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PART III
Logic of Music (Ga)

CHAPTER 8

Logical Foundations of Indian Music

Introduction

The previous chapters discussed the topics related to consonances, harmonic *swaras* and the *Tanapura* harmonics. It is evident that consonances play a vital role in the phenomenon of music generation and creating music ambience. Most dominant and musically significant consonances are already identified in Indian music as well as in Western music. Some of these consonances are known as *Shadja-Panchama Bhava, Shadja-Madhyama Bhava* and *Shadja-Gandhara Bhava* in Indian tradition. These consonances are considered the fundamental principles of music in the generative theory of Indian music (GTIM). From a music generation point of view, frequency, volume, and timbre are very important properties of sound. However, the base frequency and the associated consonances are important because they play a vital role in music generation. It does not mean that volume or timbre has no role in music. Volume and timbre are important and they have specific roles in music generation. It may be said that these factors have a secondary role while base frequency and the above-mentioned consonances have a primary role in music generation. As seen in the previous chapters, consonances and harmonics have musically significant relationships with the base frequency or the tonic in a *Saptaka*. These relations can be understood from a logical point of view as well as from a computational point of view. This chapter elaborates on the role of consonances in Indian music and develops an aural logic to provide a formal systemic structure to understand the phenomenon of music. The following sections discuss the musical concepts from a mathematical and logical point of view. The discussion indicates that a rigorous mathematical theory of Indian music is possible though that is not the purpose of this chapter. The discussion insinuates a path of modular mathematics for Indian music in the beginning and then switches over to a group theoretic approach. It is suggestive of the fact that both approaches are highly relevant for developing a mathematical theory for Indian music.

Axiomatic System for Indian Music

Indian music is based on the fundamental note Sa, which is called the *Aadhar swara.* All the other *swaras* and the entire music originates from the *Aadhar swara*. Every octave or *Saptaka* begins with Sa and there can be any number of *Saptakas*, though in practice only three *Saptakas* are prevalent. With this understanding, the description of the logical foundations of Indian music thus begins as follows.

There exists a fundamental note or the *Aadhar Swara* called `Sa'.

It also assumes that initially, the first fundamental note Sa has a `self-evident' existence and from there its instantiations can be inferred. Thus, we arrive at the first axiom of the GTIM as follows.

Axiom I: There exists a musical entity called fundamental note or *Aadhar Swara* 'Sa' which has a 'self-evident' existence. This may be termed - `*Swayambhu Bhava*' or '*Swa Bhava*' in GTIM. Let us call it an Axiom of 'self-evident' existence.

`Sa' exists.

More formally, it can be stated that there exists a Unit Set S such that it has only one element Sa and it can be represented as

S={sa}

We can define a function

swabhava(x) = x

Axiom I is the fundamental axiom of GTIM because it captures the philosophical foundations of the theory. Now we can move to the next axiom.

Therefore, 'Sa' is the fundamental element of music and there exist multiple instances of this element such as – sa, hsa, hhsa... in the higher *Saptaka* and lsa, llsa... in the lower *Saptaka*.

It means for every Sa there exists- Sa', and for every Sa' there exists Sa'', and so on.

As per the traditional theoretical understanding, as mentioned in *Sangita Ratnakara*, the instantiations of Sa have '*Dwi-Gunottara Pramana*' across the *Saptakas*. It means that if the frequency value of 'Sa' of the first *Saptaka* is 1 then the value of Sa' or the Sa of the second *Saptaka* will be 2.

We can define a function

samabhava(x) = k*x where $\{x \neq 0, k \in \{2, ½\}\}$

This function may be termed the function of octave equivalence. With this function, from any member of the base *Saptaka*, we can infer the value of the relevant member of the higher *Saptaka* or the lower *Saptaka.*

samabhava(x) = k*x where k=2.

We get Sa' = 2 * Sa and Sa'' = 2 * Sa'.

The value of Sa' of the second *Saptaka* will be 2 and the value of the Sa'' of the third *Saptaka* will be 4 and so on.

If we change the value of k = ½ then we get the value of lower *Saptaka* 'Sa. samabhava(x) = k*x where k=1/2.

It means 'Sa = 1/2 * Sa.

So, from a musical point of view for all practical purposes, every *swara* Sa has its higher or lower instantiations. Here comes the second axiom of the theory as follows.

Axiom II: For every Sa there exists its instantiations that are either higher- Sa' or lower- 'Sa and their value is decided by the constant `k', however, being the instantiations of the original entity, in all other respects they are equivalent to original 'Sa'. This may be termed as '*Sama Bhava*' or the Axiom of the octave equivalence.

Accordingly, except the value difference, all the instantiations of an entity are equivalent across the *Saptakas* from a musical point of view.

From this, we get 'Corollary' as follows.

For all *Saptakas*, we may define the base frequency by the following function.

saptakaBase (SN) = 2^{SN} * Sa. (Where SN is the *Saptaka* number, SN > 1 for higher *Saptaka* and SN < 0 for lower *Saptaka*).

In the actual practice of music, the widely used values of SN are -1, 1, and 2 comprising three *Saptakas*.

Axiom I and Axiom II are the fundamental axioms of the GTIM. Apart from these two axioms, there exist a few more axioms. These are defined as follows.

Music is based on consonances of various types as discussed in the previous chapter. One of the most prominent consonances is called *Shadja-Panchama Bhava* in Indian music. So, the consonance-based relationship between *swaras* may be considered as the third axiom called the axiom of '*Samvad Bhava*'.

Axiom III: For every Sa, there exist entities that are either higher or lower and their value is decided by the constant `k', which is musically significant and these entities are consonant with the original entity Sa in some musical sense. This may be termed as '*Samvad Bhava*'. Let us call it an Axiom of consonances. This can be formulated as follows.

samvadBhava (x, k) = k*x.

This function may be used to establish consonances. Here 'x' represents the reference frequency ('Sa') and k represents the ratio which establishes the desired consonance.

As we change the value of k we can articulate various consonances as shown below. There can be multiple versions of this function and are defined as follows.

spBhava (x, k_p) = 'Pa' (k_p = 3/2 (Pythagorean), 1.498 (ET-12), 1.506 (Bharata Muni's Scale)

This is the *'Shadja Panchama Bhava'* ('the quotient of the fifth') a generalization of the rule of fifths. Alternately this can be represented as

sp (x)= k_p * x = 'Pa' (k_p = 3/2 (Pythagorean), 1.498 (ET-12), 1.506 (Bharata Muni's Scale)

Similarly, following is the *'Shadja Madhyama Bhava'* ('the quotient of the fourth') a generalization of the rule of fourths.

smBhava (x, k_m) = 'Ma' (k_m = 4/3 (Pythagorean), 1.334 (ET-12), 1.3278 (Bharata Muni's Scale). Alternately this can be represented as

sm (x)= k_m * x = 'Ma' (k_m = 4/3 (Pythagorean), 1.334 (ET-12), 1.3278 (Bharata Muni's Scale)

The principle of consonance is a generic principle and therefore, the Axiom III is also generic in nature. There exist many consonances and all of them are related with each other. For instance, the consonance called *Shadja-Madhyama Bhava* is the inverse of *Shadja-Panchama Bhava*. It was also discussed in the previous chapters that other consonances such as *Shadja-Gandhara Bhava, Shadja-Komal Gandhara Bhava, Shadja Rishabha Bhava* and *Shadja Komala Rishabha Bhava* are derivable with the help of Axiom III.

Accordingly, the *Shadja-Gandhara Bhava* (Major Third),

sgBhava (x, k_g) = 'Ga' (k_g = 5/4) etc. or alternatively sg(x) = k_g* x = 'Ga'.

Shadja-Komala Gandhara Bhava (Minor Third) will be

skgBhava (x, k_{kg}) = 'KGa' (k_{kg} = 6/5) etc. or alternatively skg(x) = k_{kg} * x = 'KGa'.

Similarly, we will have the following.

Shadja-Rishabha Bhava (Major Second)

srBhava (x, k_r) = 'Re' (k_r = 9/8) etc. or alternatively sr(x) = k_r * x = 'Re' and

Shadja-Komala Rishabha Bhava (Minor Second)

srBhava (x, k_{kr}) = 'KRe' (k_{kr} = 16/15) etc. or alternatively skr(x) = k_{kr} * x = 'KRe'.

Other *Bhavas* or consonances can be articulated by assigning appropriate values to k. Thus, the Axiom III is an important axiom because it provides a generative tool for generating various musical consonances.

The Axiom III is fascinating because, with the value of k = 1.5, we get the consonance that is supposed to be musically and mathematically significant and responsible for the Pythagorean or Just Intonation scale. If we take the value of k = 1.498 then we get the *Shadja-Panchama Bhava* for the ET-12 scale and if we take k = 1.506 then we get the *Shadja-Panchama Bhava* of Bharata Muni's scale. This needs to be highlighted because it shows the generative capabilities of this Axiom.

Axiom III is important due to many reasons. There exists a hierarchy of consonances and the lowest in the hierarchy is considered as a dissonance or '*Vivadi Bhava*' in the musical traditions. It brings in the emotive elements in music. This will be discussed in detail in the next chapter. Similarly, there exists a hierarchy of harmonic strength in these consonances based on the Axiom III. This aspect will also be thoroughly discussed in the next chapter.

The Axiom I establishes the *Aadhar swara*. Axiom II establishes the *Aadhar swaras* for higher and lower *Saptakas*. Axiom III establishes various consonances. Now there is a need of establishing the members of a *Saptaka* with their relative distances or intervals. The Axiom IV achieves the same.

Axiom IV: For every Sa in a *Saptaka*, there exists a sequence of entities such that the distance between two consecutive entities is equal in a musically significant sense. It means a *Saptaka* or an octave is divided logarithmically. The value of the distance is decided by the constant `k'. This may be termed as '*Samavibhaga Bhava*' or the equal temperament. This may be called an Axiom of equal temperament.

As we change the value of k, we can articulate various sequences as shown below. (si) = k^i * 'Sa'.

These represent the 'scales',

k = $2^{1/12}$ gives the ET-12 scale.

k = $2^{1/22}$ gives Bharata Muni's Scale (ET-22).

In the same manner, many new equal temperament scales can be explored by assigning appropriate values to k. Thus, Axiom IV is an important axiom because it provides a generative tool for generating various equal-temperament musical scales. Popular ET-12 scale and Bharata Muni's ET-22 scales are the best examples of this Axiom. Bharata Muni's scale is very interesting because it can be generated by the application of Axiom IV i.e., *Samavibhaga Bhava* and also by using Axiom III which is the *Samvad Bhava* properly. Bharata Muni's ET-22 scale is unique and significant in many ways. From a musical point of view, it is significant because it fulfils the *Shruti-Nidarshanam* experiment and the *Gramantara* experiment mentioned in the *Natyashastra*.

You may refer the Appendix I and Appendix II at the end of this book for more information in this regard. This relationship between mathematical entities and associated musical entities (*swaras/ shrutis*) is a miracle. The issue is puzzling and is an outstanding musical-mathematical riddle.

With the help of Axiom IV, many equal temperament scales can be established. ET-19, ET-24, ET-31 and many such scales are being explored the world over that lead to microtonal music. The author has suggested the ET-110 scale for generating microtonal music based on the Bharata Muni's ET-22 scale while discussing the concept of '*Shruti Megha*' or '*Shruti Punja*' in the monograph titled 'The Doctrine of *Shrutis* in Indian Music' [Vidwans, V. V., 2016].

The Domain of Description and Musical Scales

As already discussed, the existence of fundamental note Sa is logically articulated and established with Axiom I. The Axiom II helps establish *Saptakas* and the Axiom III provides a vital logical device to generate various consonances. For establishing other member *swaras* as well as *shrutis* (microtones) of the *Saptaka* it becomes essential to develop a robust logical structure. Axiom IV establishes equal temperament scales. Currently, as far as the musical practices that are prevalent in India are concerned, there are multiple diverse practices of establishing *swaras* in a *Saptaka*. The most popular system is known as the ET-12 system. This is popular and useful in Western music as well as in contemporary Indian music. The other important system in Indian tradition is Bharata Muni's ET-22 *shruti* system. To understand subtle aspects of musical scales in India the description of the ET-12 scale followed by Bharata Muni's ET-22 *shruti* system is provided here. In the previous chapters, the author has suggested the HS-12 (harmonic *swaras* scale) which is an overlay on the ET-22. Therefore, it need not be considered as a separate scale.

In all the above discussion, the domain of description is the set of all the musically usable audible/ aural frequencies ranging approximately from 20 Hertz to 20,000 Hertz. A very large domain. These frequencies are represented by real numbers and Sa will never be equal to zero Hertz. Once we keep this broader musical context at the back of our minds, it becomes easier to understand the underlying abstract musical logical structure.

Let us assume that there exists a large domain of all possible frequency values for musical notes from which specific frequency values for notes are chosen. Let us call this larger domain MD. The *Aadhar swara* is chosen from this domain MD. With the help of Axiom I and Axiom II fundamental notes and the *Saptaka* are established. The musical scale can be established with the help of Axiom IV. With this, we can explore the possibilities of describing ET-12 and ET-22 scales.

ET-12 Scale: Let us begin with the ET-12 scale. The ET-12 system assumes that an octave or a *Saptaka* is divided into 12 musically equal parts. Each note in the *Saptaka* can be established by multiplying the previous note by a constant value `k'. The value of `k' is where the actual value is 1.0594630944.

ET-12 is a set that has 12 *swara* elements placed at equal (logarithmically equal, not linearly equal) distances given by the equal temperament ratios. Let us denote this ratio by r, we know that the frequency of the x^{th} *swara* is given by,

$f(r, x) = r^x \times$ 'Sa', where x represents the 'note number'.

Therefore, we can generate a mapping between 'note number' and frequency as follows.

$ET12 = \{(x, f(k, x) \mid x \neq 0, f(k,x) \in MD\}$

Apart from the domain MD mostly in the case of classical music the *Tanapura* provides a musical context which itself is a subset of MD. The Tanapura helps in the establishment of the ambience based on the consonances- either *Shadja-Panchama Bhava* or *Shadja-Madhyama Bhava*. Axiom III plays an important role in this regard. However, it is very specific to Indian classical music. The *Tanapura* may not be used in the case of light music or folk music. At times some other instruments or a set of other instruments are used as an orchestra and they provide the musical context. So let us call this kind of musical context a `Musical Context Domain'. This may be referred to as the domain MCD. The MCD is a subset of MD.

So, $MCD \subset MD$.

So, the ET12 scale can be represented as

$ET12 = \{(x, f(k, x) \mid x \neq 0, f(k,x) \in MCD\}$

The frequencies generated by MCD are also a huge set that includes major frequencies, harmonics and upper partials as well. So, it can be assumed that frequencies generated by ET12 are a subset of the MCD.

ET-22 Scale: Now let us try to understand how to represent Bharata Muni's system in this way. Bharata Muni's music was based on the equal temperament 22 *shrutis*. The equal temperament ratio for this system is 22^{nd} root of 2 i.e., or 1.0320082797. It means if we multiply the frequency value of *swara* 'sa' by 1.0320082797 then we get the frequency value of the next *shruti* and we can continue the process till we get all the 22 *shruti* values. So let us call this ratio as P_{shr} (*Pramana Shruti Ratio*). This is just the value of 'r' for Bharata Muni's scale.

Thus $P_{shr} = 1.0320082797$.
So, in the context of Bharata Muni's system this system can be represented as

$f(P_{shr}, x) = (P_{shr})^x \times$ 'Sa'

Thus, the set of 22 *shruti* ET22 may be represented as follows.

ET22 = {(x, f (P_{shr}, x) | x ∈ MD}

After taking into account the musical context generated by *Tanapura* or some other instrument/s it may be represented as

ET22 = {(x, f (P_{shr}, x) | x ∈ MCD}

Mapping ET22 onto ET12

Here it should be clarified that all the above representation is a logical/ mathematical abstraction of the real system. Therefore, the frequency values of 'x' generated either in the ET12 system or the ET22 system may not be rendered with precision in actual practice. These values provide the theoretical reference points. The mathematical values make that region of musical frequencies stronger and *swaras* or *shrutis* rendered by the performers fall broadly within that region. ET12 system as well as ET22 system support the performers to locate the *swara* frequencies as closer as possible to these regions. Thus, ET22 can be mapped onto ET12. This can be shown as follows. This is a surjective mapping.

ET22 = {(csa, sa), (ckre, kre), (bkre, re), (bga, kga), ga, (cma, ma), (cmat, mat), (cpa, pa), (ckdha, kdha), (bdha, dha), (bni, kni), ni}

ET12 = {sa, kre, re, kga, ga, ma, mat, pa, kdha, dha, kni, ni}

This does not mean that the *shrutis* placed in the brackets are the same. It means that they fall in the same region. For instance, bga and kga are not the same *shrutis* but still they can be put together. Musical performers may consider them as equivalent because they are very close to each other. In *Raga Darbari Kanada Ati Komal Gandhara* – bga is used but Harmonium does not have a key for *Ati Komal Gandhara* so it is accommodated with the *Komal Gandhara* key.

There are many instances where such an approximation is done by performers and it does not affect the overall aesthetic experience.

The same may be represented in a more abstract way as follows:

ET22 = {s_i | $s_i = (P_{shr})^i$ * 'Sa', -1 < i < 23} and will be represented as follows.

ET22 = {s_{22}, s_1, s_2, s_3, s_4, s_5, s_6, s_7, s_8, s_9, s_{10}, s_{11}, s_{12}, s_{13}, s_{14}, s_{15}, s_{16}, s_{17}, s_{18}, s_{19}, s_{20}, s_{21}}.

ET22 = {{s_{22}, s_1}, {s_2, s_3}, {s_4, s_5}, {s_6, s_7}, {s_8}, {s_9, s_{10}}, {s_{11}, $s_{12\}}$, {s_{13}, $s_{14\}}$, {s_{15}, s_1}, {s_{17}, s_{18}}, {s_{19}, s_{20}}, {s_{21}}}.

ET12 = {x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}}.

ET22, and ET12 sets have a special relationship with each other. Respective pairs of elements from ET22 can be mapped onto respective elements of the ET12. Only two elements are not in pairs from ET22 set. The mapping can be worked out as follows.

ET22→ ET12:

ET-22	$\{s_{22}, s_1\}$	$\{s_2, s_3\}$	$\{s_4, s_5\}$	$\{s_6, s_7\}$	$\{s_8\}$	$\{s_9, s_{10}\}$	$\{s_{11}, s_{12}\}$	$\{s_{13}, s_{14}\}$	$\{s_{15}, s_{16}\}$	$\{s_{17}, s_{18}\}$	$\{s_{19}, s_{20}\}$	$\{s_{21}\}$
ET-12	$\{x_1\}$	$\{x_2\}$	$\{x_3\}$	$\{x_4\}$	$\{x_5\}$	$\{x_6\}$	$\{x_7\}$	$\{x_8\}$	$\{x_9\}$	$\{x_{10}\}$	$\{x_{11}\}$	$\{x_{12}\}$
	Sa	KRe	Re	KGa	Ga	Ma	Mat	Pa	KDha	Dha	KNi	Ni

Therefore, it may be said that ET22 can be mapped onto ET12 and there exists a special relationship between them. It follows from the mapping that at a certain abstract level for all theoretical descriptions ET12 can be taken as a base reference set. It entails that all the descriptions and analysis of ET12 can be translated and interpreted for ET22 set as shown above.

With this understanding here an attempt is made to arrive at a generalized system for Indian music that accommodates the ET-12 system as well as Bharata's ET-22 *shruti* system. Let us call the system SS12 an abstraction of the ET-12 system and ET-22 system. From a mathematical abstraction point of view, SS12 is a nomenclature used for abstract logical operations performed on musical entities called *swaras/ shrutis*. This abstraction entails that any operation that generates valid results in SS12 must generate valid results in ET-12 and ET-22. So henceforth the nomenclature SS12 is used to represent the 12 *swara* abstract system.

In the musical parlance, there exists a smaller set made up of 7 *swaras*. As per the musical practice, SS12 can be mapped onto SS7. A surjective mapping of SS12 onto SS7 is possible as shown below.

Mapping of SS12 onto SS7 will be as follows:

f: SS12 → SS7

SS12	Sa	kre, re	kga, ga	ma, mat	pa	kdha, dha	kni, ni
SS7	Sa	re	ga	ma	pa	dha	ni

Overview of the mappings of SS22, SS12 and SS7 is as follows.

ET22	{csa, sa}	{ckre, kre, bkre, re}	{bga, kga, ga}	{cma, ma, cmat, mat}	{cpa, pa}	{ckdha, kdha), (bdha, dha}	{bni, kni, ni}
ET12	Sa	kre, re	kga, ga	ma, mat	pa	kdha, dha	kni, ni
SS7	Sa	re	ga	ma	pa	dha	ni

An issue of particular interest at this juncture concerns the musicality of the *swaras* and *shrutis*. As anyone with even a cursory interest in music knows, a musical note is much more than just the associated frequency. In music, notes and melodic patterns are the warps and wefts that contribute to the eventual musical tapestry. The significance of a note when compared to a composition is minuscule, but this does not entail that the individual melodic characteristics of a note are negligible. If notes are treated as pure frequencies, without any associating qualities such as volume, timbre, duration, accentuation etc. then the musical macrocosm will be stripped bare, leaving behind a scarce semblance of its erstwhile magnificence. Therefore, a complete mathematical description will have to account for all these factors. The determination of the manner of mathematical representation of the musical qualities of a note is therefore an outstanding issue at present. We may assign a certain 'musical attribute' to each note, we denote this musical attribute by 'S'. This attribute shall be a mathematical entity (whose exact nature is at present undefined). Then, whilst representing the set SS12, instead of defining each element to be the frequency f (r, x), we may define each element to be the 'attribute' S (r, x).

The set SS12 may be defined more rigorously as:

$SS12 = \{(x, S(r, x) \mid x \neq 0, S(r,x) \in \text{Augmented MCD}\}$

Now we turn towards certain important theoretical results of the GTIM that bridge the mathematical and computational realities.

Modular Mathematics and Musical Scales

Researchers who are interested in the modular mathematics of music prefer to represent the ET-12 scale in terms of numbers. It is possible to introduce the integer model of pitch, which assigns to each of the 12 *swaras* an integer mod 12. The transpositions and inversions are musically significant operations that can be operated on them which have inputs and outputs that are pitches [Fiore, T. M, 2009, pp. 11-12]. In the Indian system of music, the operations of transposition and inversion are not directly relevant. But the integer model of the pitch with mod 12 applies to ET-12 in terms of consonances. It is possible to define an operation called '*Bhava*' meaning consonance between pitch intervals or any two members of ET-12.

Consonance or '*Bhava*' is very significant to Indian music. Consonances are directly applied to *Raga* music. When we hear a piece of melodic music consisting of *Raga*-specific *swaras*, we hear the intervals between the individual *swaras*. Intervals are nothing but consonances. The relationship between these intervals is what makes a melody appealing to us. We discussed the significance of consonances and their relationship with each other earlier. Thus, the intervals or consonances can be understood from modular functions in the ET12 set. In ET12 set the *swaras* are placed in equal temperament. The unit distance between two consecutive *swaras* is that of a semitone. With these intervals, the relationship between pairs of *swaras* can be understood. Let us try to understand these relations through the function called *Bhava*. In modular mathematics, the *Bhava* or consonance function can be very useful in this sense to describe various intervals.

Modular Mathematics with ET12 scale: Let us begin with ET-12 system. The ET-12 system assumes that an octave or a *Saptaka* is divided into 12 musically equal parts. Each note in the *Saptaka* can be established by multiplying the previous note by a constant value `k'. The value of `k' is where the actual value of is 1.0594630944.

Therefore, *swaras* for ET-12 can be represented as follows.

ET12 = {sa, kre, re, kga, ga, ma, mat, pa, kdha, dha, kni, ni}

We may construct a table of exponents for the *swaras* of ET-12 as follows. As should be obvious by now, this tabular form is simply the 'note number' of the *swaras*.

For the middle octave or *Madhya Saptaka,* the representation will be as follows.

$ET12_M$ = {sa, kre, re, kga, ga, ma, mat, pa, kdha, dha, kni, ni}

Let us have the integer representation of the ET12 by a set SN12 as follows.

$SN12_M = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11\}$

For the lower octave or *Mandra Saptaka* the representation will be as follows.

$ET12_L$ = {sa, ni, kni, dha, kdha, pa, mat, ma, ga, kga, re, kre}

$SN12_L = \{0, -1, -2, -3, -4, -5, -6, -7, -8, -9, -10, -11\}$

Accordingly, we may represent the ET-12 scale numerically as follows. Let us call integer representation of ET12 as SN12 for modular operations.

$SN12 = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11\}$

The function *Bhava* can be defined as follows: Let *n* be an integer mod 12. Then the function B_n: SN12 → SN12 is defined by the formula $B_n(x) = x + n \bmod 12$ is called consonance by n.

Some examples for B_7 : SN12 → SN12 are as follows. They represent the *Shadja-Panchama Bhava* as *Panchama* is the seventh *swara* from the *Shadja swara*. Following are the examples of *Shadja-Panchama Bhava* for some important *swaras* of the SN12 scale. Following representation of ET12 can be good reference to understand this phenomenon.

$B_7(0) = 0 + 7 = 7 \bmod 12$ from Sa to Pa

$B_7(2) = 2 + 7 = 9 \bmod 12$ from Re to Dha

$B_7(4) = 4 + 7 = 11 \bmod 12$ from Ga to Ni

$B_7(5) = 5 + 7 = 12 \bmod 12$ from Ma to Sa (Higher Sa becomes Sa)

$B_7(7) = 7 + 7 = 14 = 2 \bmod 12$ from Pa to Re (Higher Re becomes Re)

$B_7(9) = 9 + 7 = 16 = 4 \bmod 12$ from Dha to Ga (Higher Ga becomes Ga)

$B_7(11) = 11 + 7 = 18 = 6 \bmod 12$ from Ni to Mat (Higher Mat becomes Mat)

SN12 = {0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11}

SN12 has 12 members so the cardinality of SN12 = 12.

It can be represented as | SN12| = 12.

There exists a set of ordered pairs as follows.

<|-1|, |11|>, <|-2|, |10|>, <|-3|, |9|>, <|-4|, |8|>, <|-5|, |7|>, <|-6|, |6|>, <|-7|, |5|>, <|-8|, |4|>, <|-9|, |3|>, <|-10|, |2|>, <|-11|, |1|>

The addition of the members in each ordered pair leads to the absolute value 12 which is the

cardinal value of the set. This shows that this set is self-sufficient in various ways and musically so too. Each of the above-ordered pair is a pair of complimentary members. It means in the pair, <|-1|, |11|>, from a musical point of view, -1 is nothing but the lower 'ni' i.e., 'lni' and 11 is the 'ni'. Similarly, in the case of <|-11|, |1|>, here -11 stands for lower 'kre' i.e., 'lkre' and 1 represents 'kre'.

<|-1|, |11|> = < 'lni', 'ni'> and < 'lkre', 'kre'>

So set SN12 is highly interesting from a musical point of view.

If we take the following representation for description then that will be also musically and computationally insightful.

SN12 = {0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11} Here, 0 = 'sa' and 11 = 'ni'.

As it is mentioned above that the cardinality of SN12 is 12, then many interesting conclusions can be derived as follows.

If we take two numbers whose addition is 12 then they happen to be consonant with 'sa' by the *Samvad Bhavas* that are inverse of each other. For example, 5+7=12. Here 5 stands for *swara* 'ma' and 7 stands for *swara* 'pa'. Interestingly, both the *swaras* are generated from the fundamental *swara* 'sa' by application of the same generative rule, the *Samvad Bhava*. When we multiply the frequency of 'sa' by the *Shadja-Panchama Bhava* we get the *swara* 'pa'. Similarly, when we divide the frequency of 'sa' by the *Shadja-Panchama Bhava* we get the *swara* 'ma' of the lower octave. In this sense, *Shadja-Panchama Bhava* and *Shadja-Madhyama Bhava* are the inverse laws of each other. This is true with four other relations such as (4, 8), (3, 9), (2, 10), and (1, 11) pairs also.

Modular Mathematics with ET22 scale: For Bharata Muni's ET22 scale, following representations will be appropriate to understand the modular mathematics of intervals/ consonances. In this case the function *Bhava* can be defined as follows: Let *n* be an integer mod 22. Then the function B_n: ET22 → ET22 is defined by the formula $B_n(x) = x + n \bmod 22$ is called consonance by n.

ET-22 can be represented as follows.

ET22 = {sa, ckre, kre, bre, re, bga, kga, ga, cma, ma, cmat, mat, cpa, pa, ckdha, kdha, bdha, dha, bni, kni, ni, csa}

We may construct a table of exponents for the *swaras* of ET-22 as follows. As should be obvious by now, this tabular form is simply the 'note number' of the *swaras*. Here again the integer representation is denoted by the set SN22.

For the middle octave or *Madhya Saptaka,* the representation will be as follows.

$ET22_M$ = {sa, ckre, kre, bre, re, bga, kga, ga, cma, ma, cmat, mat, cpa, pa, ckdha, kdha, bdha, dha, bni, kni, ni, csa}

$SN22_M$ = {0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21}

For the lower octave or *Mandra Saptaka* the representation will be as follows.

$ET22_L$ = {sa, csa, ni, kni, bni, dha, bdha, kdha, ckdha, pa, cpa, mat, cmat, ma, cma, ga, kga, bga, re, bre, kre, ckre}

$SN22_L$ = {0, -1, -2, -3, - 4, -5, -6, -7, -8, -9, -10, -11, -12, -13, -14, -15, -16, -17, -18, -19, -20, -21}

In the case of SN22, the unit distance is called a '*Pramana Shruti*'. *Natyashastra* provides the description of consonances in terms of intervals between *swaras* and *shrutis*. The distance between *Shadja* and *Panchama swara* is supposed to be 13 *shrutis* while distance between *Shadja* and *Madhyama swaras* is supposed to be of 9 *shrutis.* Similarly, there is a mention of *4 shruti Pramana, 3 shruti Pramana* and 2 *shruti Pramana* in the *Natyashastra*. These intervals are nothing but various consonances or dissonances. With these intervals relationship between pairs of *shrutis* can be understood. Let us try to understand these relations through the function called *Bhava* for SN22 scale.

Some examples for B_{13}: SN22 → SN22 are as follows. They represent the *shadja-Panchama Bhava* as *Panchama* is the thirteenth *shruti* from the *Shadja swara*.

Some examples for B_{13}: SN22 → SN22 are

$B_{13}(0) = 0 + 13 = 13 \mod 22$ from Sa to Pa

$B_{13}(4) = 4 + 13 = 17 \mod 22$ from Re to Dha

$B_{13}(7) = 7 + 13 = 20 \mod 22$ from Ga to Ni

$B_{13}(9) = 9 + 13 = 22 = 0 \mod 22$ from Ma to Sa (Higher Sa becomes Sa)

$B_{13}(13) = 13 + 13 = 26 = 4 \mod 22$ from Pa to Re (Higher Re becomes Re)

$B_{13}(17) = 17 + 13 = 30 = 8 \mod 22$ from Dha to Ga (Higher Ga becomes Ga)

$B_{13}(21) = 21 + 13 = 34 = 11 \mod 22$ from Ni to Mat (Higher Mat becomes Mat)

$SN22_M = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21\}$

Thus, it is evident that modular mathematics for Indian music is insightful. So let us develop the GTIM system further based on this understanding.

Towards the Group Theoretic Representations

First, we harken back to the representation of *swaras* as a table of exponents and recall that it also encodes the note numbers. Therefore, the subsequent discussion treats the set SN12 to be in the following representation.

SN12 = {0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11}

Here, 0 = 'sa' and +11 = 'ni' but -11 = kre by the modular operation. It will be clear as per the following representations of SS12.

For the middle octave or *Madhya Saptaka,* the representation will be as follows.

$ET12_M$ = {sa, kre, re, kga, ga, ma, mat, pa, kdha, dha, kni, ni}

$SN12_M = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11\}$

For the lower octave or *Mandra Saptaka* the representation will be as follows.

$ET12_L$ = {sa, ni, kni, dha, kdha, pa, mat, ma, ga, kga, re, kre}

$SN12_L = \{0, -1, -2, -3, -4, -5, -6, -7, -8, -9, -10, -11\}$

The Union set of $ET12_M$ and $ET12_L$ that is $ET12_M \cup ET12_L$ may called $ET12_{ML}$ and can be represented as follows.

$ET12_{ML}$ = {lkre, lre, lkga, lga, lma, lmat, lpa, lkdha, ldha, lkni, lni, sa, kre, re, kga, ga, ma, mat, pa, kdha, dha, kni, ni}

$SN12_{ML}$ = {-11, -10, -9, -8, -7, -6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11}

With this understanding, now let us position this in group theoretic modelling. A group is a set with a way to combine elements similar to the way that one adds or multiplies numbers. We are concerned with the musical operations of consonance such as *Shadja-Panchama Bhava* etc. For a musical group, the operation would be any of the interval relations between any two *swaras* mentioned in the Axiom III called '*Samvad Bhava*'. In other words, consonances are the musical operations that can be performed in a group.

Definition: A group G is a set G equipped with a function *: G * G → G which satisfies the following group axioms. The operation '*' is very similar to addition.

The group axioms are as follows:

(1) For any three elements a, b, and c of G we have $(a * b) * c = a * (b * c)$, *i.e.,* the operation '*' is associative.

(2) There is an element e of G such that a * e = a = e * a for every element a of G, i.e., the element e is the identity element of the group.

(3) For every element a of G there is an element a^{-1} such that $a * a^{-1} = e = a^{-1} * a$, i.e., every element a has an inverse a^{-1}.

Now the way we have defined SS22, SS12, and SS7 above qualifies the definition of a group. Let us understand how these sets fulfil all three axioms of a group G. We need to remember that G is a group of musical entities.

The first axiom is known as the axiom of associativity. It means if we take any three *swaras* of a *Saptaka* then for instance, (sa * ga) * pa = sa * (ga * pa). The left part of the equation means that if we play sa and pa *swaras* together and then add pa to it then the resultant consonance effect is equivalent to the consonance effect produced by first playing sa *swara* and then adding the ga and pa *swaras* together that is the right side of the equation. In the context of Western music, this forms a chord. In the context of Indian music, as we discussed in the previous chapters this results in an implied harmony. The operation '*' is nothing but the addition of two *swaras*.

The second axiom is called the axiom of identity. In musical parlance, the swara sa is the identity element. It means that *swara* sa is a neutral *swara*. As we know when we keep playing *swara* sa on a *Tanapura*, it creates an ambience possessed with *swara* sa. On that background, if we render any other *swara* such as pa or ma, it will stand out. Similarly, if we are rendering pa or ma *swara* and then we start playing *Tanpura* with swaras sa alone, then the same ambience will be created and again the other *swara* pa or ma will stand out as before. Therefore, pa * sa = pa = sa * pa or ma * sa = ma = sa * ma. The same is true for every element of the group.

The third axiom is called the axiom of inverses. It means that in a group every element has its inverse as a group member. As it is known that the consonance of *Shadja-Panchama Bhava* has its inverse of *Shadja-Madhyama Bhava* and accordingly *swara* pa and *swara* ma are inverses of each other. Both of these swaras are the members of a group.

Therefore, all three axioms of a group are valid in the case of SS22, SS12 and SS7. We can represent them as G22, G12 and G7 respectively. If we take the G12 as a group for analysis many musically significant results can be achieved. It is discussed as follows.

$SS12_{ML}$ = {kre, re, kga, ga, ma, mat, pa, kdha, dha, kni, ni, sa, kre, re, kga, ga, ma, mat, pa, kdha, dha, kni, ni}

$SS12_{ML}$ can be represented as $GN12_{ML}$ in numerical form as follows.

$GN12_{ML}$ = {-11, -10, -9, -8, -7, -6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11}

The above representation of $SS12_{ML}$ as $GN12_{ML}$ can be helpful for many computational applications and therefore it is very important.

Sa as it is known, 'sa' is a tonic or a fundamental note in Indian music. As already seen, it is also a generative note. This leads to interesting implications. We can generate ordered pairs as follows.

<-1,1>, <-2,2>, <-3,3>, <-4,4>, <-5,5>, <-6,6>, <-7,7>, <-8,8>, <-9,9>, <-10,10>, <-11,11>

It is interesting to note that the group operation '*' on the members of these ordered pair is 0 which is an identity element. For example, -1 +1 = 0 or -11+11 = 0 and so on. It means that in every ordered pair of the members of $GN12_{ML}$, each member of the pair has a nullifying effect on the other or they are musically opposite of each other. This property allows us to define various consonances in Indian music. In $GN12_{ML}$ it can be stated that all the members of the ordered pairs whose addition is '0' or the 'identity' belong to some or other consonances. For example, in ordered pair <-4,4>, -4 stands for lkdha and 4 stands for ga. From a musical point of view, both of them have a '*Gandhara Bhava*' relationship with the identity element 'sa'.

The discussion so far about the modular representation and the group-theoretic representation of Indian music is strictly indicative and not rigorous. But in a way that does not trivialise it.

At this stage of the development of logical and computational foundations of Indian music from a larger domain or the universe called MD a specific musical context can be defined as MCD and from there onwards multiple possibilities of more well-defined sets of *swaras/ shrutis* can be envisioned and explored. Specifically, ET22 as a Bharata Muni's set of equal temperament twenty-two *shrutis*, a contemporary popular set of ET12 as the equal temperament 12 *swaras* can be established as SS12. At a very abstract and generalized level, all these three sets can be further abstracted as a set called SS7 which is made up of seven *swaras*. For performing various computational operations these two sets- SS12 and SS7 can become a very handy device and therefore, throughout this book, these two sets will be referred to during the discussion. Modular processing on these two sets and the group-theoretic concepts developed in this regard are further extended in the chapters dedicated to the *Raga* generation process.

It is often said that Indian music is highly scientific but in what sense it is scientific is very rarely explained. This chapter tried to provide a logical frame-work for such a discourse. At an abstract conceptual and mathematical level, it is possible to envisage Indian music as a logico-mathematical paradigm where basic building blocks of Indian music can be identified and a rigorous logical system can be developed. The next chapter deals with the laws of musical logic relevant to Indian music.

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CHAPTER 9

Laws of Musical Computing

Introduction

Any system needs two types of entities: a basic set of elements and a set of rules to operate on them. In the case of Indian music *swaras* and *shrutis* form the required set of basic elements. However, finding a set of rules that operate on them is a complex task. Fortunately, Bharata Muni's *Natyashastra* provides some good grounding, as it has mentioned two important laws of music- *Shadja-Panchama Bhava* and *Shadja-Madhyama Bhava*. In previous chapters, these two laws are discussed from a logical and mathematical perspective. These are the laws of musical consonance that establish significant musical and aesthetic relationships between *swaras* and *shrutis*. The performers as well as the audience experience these relationships intuitively which results in aesthetic pleasure. The nature of these laws is such that if we know one *swara* or a *shruti* then one can infer the next *swara* or *shruti* from it for a musical phrase based on these laws. Therefore, in this sense, these are the laws of musical inferences. Therefore, these laws are suitable for musical computing. They are also the laws of musical intelligence. Musical intelligence is the ability to perceive, distinguish, transform, and express sounds and musical forms. It allows people to create, communicate and understand musical meaning through sound. This intelligence includes sensitivity to the rhythms, melodies, and tones of a piece of music. [Gardner, H., 2011, pp. 105-134]. From this perspective, the laws that are being discussed in this chapter are the laws of musical intelligence. This chapter is dedicated to developing a formal and theoretical framework of musical logic in general keeping Indian Music as the focus. An attempt is made to develop a system of laws of musical logic for Indian music that can be eventually manifested in an Artificial Musical Intelligence system.

As already discussed in the previous chapters, these two laws- *Shadja-Panchama Bhava and the Shadja-Madhyama Bhava*, are based on the 'Arithmetic Mean' and the 'Harmonic Mean' respectively. As discussed earlier, it is possible to develop a scheme of other secondary laws based on these two laws. There exists a hierarchy of such second line of laws as *Shadja-Gandhara Bhava (SG), Shadja-Komal Gandhara Bhava (SKG), Shadja-Rishabha Bhava (SR) and Shadja-Komal Rishabha Bhava* (SKR) and so on. Apart from this set of hierarchical laws, there are other laws which are equally important for understanding the musical processes that have logical, mathematical, and psycho-acoustic dimensions. This chapter, thus discusses the set of laws called the laws of musical logic (LML), and other laws such as the Law of Harmonic Strength, the Law of Emotive Strength, the Law of *Nitya Swaras* and most importantly the Law of Co-existence of *Swaras*. All these laws have a very active and seminal role in shaping Indian music. These laws are completely new additions to the repertory of Indian music. Laws of musical logic are inspired by the *Natyashastra* but other laws are the result of the research and investigations into traditional and contemporary musical practices by the author of this book. These investigations were conducted for the development of the *AIRaga* system and *AITala* system and therefore, it can be conclusively said that these laws are seminal to GTIM and Indian computational music.

Laws of Musical Logic (LML)

LML stands for a set of aural laws- *Shadja-Panchama Bhava*- SP, *Shadja-Madhyama Bhava*- SM and their derivative laws like *Shadja-Gandhara Bhava (SG), Shadja-Komal Gandhara Bhava (SKG), Shadja-Rishabha Bhava (SR) and Shadja-Komal Rishabha (SKR)*. These LMLs can be applied to the members of the sets of

Arohi swaras A = {Sa, KRe, Re, KGa, Ga, Ma, Mat, Pa, KDha, Dha, KNi, Ni, HSa}

and

Avrohi swaras D = {HSa, Ni, KNi, Dha, KDha, Pa, Mat, Ma, Ga, KGA, Re, KRe, Sa}.

These are also applicable to other important *swaras* such as *Vadi, Samvadi, Anuvadi,* and *Anu-Anuvadi swaras*. For instance, the *Vadi* and *Samvadi* should adhere to LML SP and LML SM. All these laws of musical logic (LML) are musically significant relations or functions between musical entities called *swaras* or the members of the set SS12. (This set SS12 is discussed in the previous chapter.) There are eight such laws as mentioned below.

LML = {SS, SS’, SP, SM, SG, SKG, SR, SKR}

The LML is a distinct set of laws made up of rules that are based on the relative consonance of each member entity of SS12 that is each *swara*. While discussing the four fundamental axioms of GTIM these laws are already discussed from a logical point of view. There exists a hierarchy of these laws and associated consonances. The first four laws of this group namely, SS, SS', SP, SM are the primary laws. The rest of the laws are secondary laws because they can be derived from the primary laws. Out of these SM is an inverse of SP so it is derivable from SP but still it helps in deriving remaining laws it is considered as a primary law. All these LMLs are known as the rules of consonance and are understood from a musical point of view in India and in the West. In GTIM, they are considered basic axioms of the system for three reasons. Firstly, these rules are the laws of aural inference or musical logic that has psycho-acoustic dimension apart from having a basis in physics and mathematics. These rules of aural inference are very important and are the foundational stones of the system GTIM. Secondly, these rules help in generating other rules of musical inference as well as other rules such as the Law of Co-existence of *Swaras* and others. They have the generative capacity. Thirdly and most importantly, these rules help in explaining and substantiating conventional practices and norms in traditional Indian music. Except for the first two laws, all the LMLs are discussed, derived and proved in the previous chapter by using the ratios of 'Arithmetic Mean' and 'Harmonic Mean'. So now let us attempt to understand these laws for their manifestation in the GTIM.

All the LMLs are described by taking a set SS12 as the basic domain of description. Even for other sets such as ET12 and even ET22, this description is extendable.

SS12 = {sa, kre, re, kga, ga, ma, mat, pa, kdha, dha, kni, ni}

For all the following operations

f: SS12 → SS12

It means the domain set for all the operations is SS12 and the range of all the solutions will be the set SS12. This helps in performing modular mathematical operations on this set so it will be useful to represent the SS12 as follows

$SS12_m = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11\}$

$SS12_m = \{0, 1, 2, 3, \ldots m-1\}$ where m = 12. This will help in performing all modular functions on the aforementioned function f: SS12 → SS12 will become as

$f: SS12_m \rightarrow SS12_m$

With these basics, we can describe all the LMLs as follows.

LML SS (*Swa-Bhava*):

This is the axiom called '*Swa-Bhava*'. It means any member entity in SS12 is derivable from itself.

∴ ss(sa) = sa.

As a result

∴ ss(re) = re and so on.

In a *Raga* rendering when a performer renders a particular *swara* again and again this rule is in use. This is also known as a *Sthayi Varna* in Indian tradition.

LML SS' (*Sama-Bhava*):

This is the axiom called '*Sama-Bhava*'. It means any member entity of SS12 has its replica in another set called SS12'.

∴ ss'(sa) = sa'.

As a result

∴ ss'(re) = re' and so on.

Examples of SS12' could be shown as

SS12' = k*SS12 meaning there by a new set is generated by multiplying the frequency value of each member of SS12 by k in the same order. If k = 2 then the following set will be generated.

SS12' = {2*frequency of sa, 2* frequency of kre, ...}

This rule helps in generating higher and lower *Saptakas* of music. When a performer is rendering *swaras* sa and then jumping directly to the higher sa which is a sa of the higher *Saptaka*, this rule is in use. If we take k = 1/2, then the value of each member of SS12 will be divided by 2 and a lower *Saptaka* will be generated.

LML SS and LML SS' are core rules. The remaining laws follow certain patterns for all modular processing. $SS12_m$ is the base set for modular processing.

SS12 = {sa, kre, re, kga, ga, ma, mat, pa, kdha, dha, kni, ni} $SS12_m$ = {0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11}

$SS12_m$ is the modular set for SS12 such that sa =0, kre =1, re =2, kga =3, ga =4, ma =5, mat =6, pa =7, kdha =8, dha =9, kni =10, ni =11.

LML SP *(Shadja-Panchama Bhava):*

This is a very important rule which is traditionally known as '*Shadja-Panchama Bhava*'. In Western music, it is known as the rule of fifths. For the modular processing if you add the number 7 to any member of the set $SS12_m$ then you get the resultant member that is consonant with the original *swara* by the *Shadja-Panchama Bhava*.

∴ sp(sa) = pa.

∴ 0 + 7 = 7, this is *swara* pa in SS12 As a result

∴ sp(re) = dha and so on.

∴ 2 + 7 = 9, this is *swara* dha in SS12

LML SM *(Shadja-Madhyama Bhava):*

This is known as *Shadja-Madhyama Bhava* in Indian music and in Western music it is known as the rule of fourths. It is the inverse of *Shadja-Panchama Bhava*. For the modular processing if you add the number 5 to any member of the set $SS12_m$ then you get the resultant member that is consonant with the original *swara* by the *Shadja-Madhyama Bhava*.

∴ sm(sa) = ma.

∴ 0 + 5 = 5, this is *swara* ma in SS12 As a result

∴ sm(re) = pa and so on.

∴ 2 + 5 = 7, this is *swara* pa in SS12

Since it is an inverse of *Shadja-Panchama Bhava*, it can be derived by subtracting 7 from the modulo value 12.

∴ sm(sa) = ma.

∴ 12 - 7 = 5, this is *swara* ma in SS12 As a result

∴ sm(re) = pa and so on.

∴ (12+2) =14 - 7 = 7, this is *swara* pa in SS12

LML SG (*Shadja-Gandhara Bhava*):

This is known as *Shadja-Gandhar Bhava* in Indian music and in Western music it is known as the rule of third. For the modular processing if you add the number 4 to any member of the set $SS12_m$ then you get the resultant member that is consonant with the original *swara* by the *Shadja-Gandhar Bhava*.

∴ sg(sa) = ga.

∴ 0 + 4 = 4, this is *swara* ga in SS12 As a result

∴ sg(re) = mat and so on.

∴ 2 + 4 = 6, this is the *swara* mat in SS12

The inverse of LML SG is LML SKD. We get the value of LML SKD by subtracting 4 from modulo value 12.

∴ skd(sa) = kdha.

∴ 12 - 4 = 8, this is *swara* kdha in SS12 As a result

∴ skd(re) = kni and so on.

∴ (12 +2) = 14- 4 = 10, this is *swara* kni in SS12

LML SKG *(Shadja-Komal Gandhara Bhava):*

This is known as *Shadja-Komal Gandhar Bhava* in Indian music. For the modular processing if you add the number 3 to any member of the set $SS12_m$ then you get the resultant member that is consonant with the original *swara* by the *Shadja-Komal Gandhar Bhava*.

∴ skg(sa) = kga.

∴ 0 + 3 = 3, this is *swara* kga in SS12

As a result

∴ skg(re) = ma and so on.

∴ 2 + 3 = 5, this is *swara* ma in SS12

Inverse of LML SKG is LML SD. We get value of LML SD by subtracting 3 from modulo value 12.

∴ sd(sa) = dha.

∴ 12 - 3 = 9, this is *swara* dha in SS12

As a result

∴ sd(re) = ni and so on.

∴ (12 +2) = 14- 3 = 11, this is *swara* ni in SS12

LML SR *(Shadja-Rishabha Bhava):*

This is known as *Shadja-Rishabha Bhava* in Indian music. For the modular processing if you add number 2 to any member of the set $SS12_m$ then you get the resultant member that is consonant with the original *swara* by the *Shadja-Rishabha Bhava*.

∴ sr(sa) = re.

∴ 0 + 2 = 2, this is *swara* re in SS12 As a result

∴ sr(re) = ga and so on.

∴ 2 + 2 = 4, this is *swara* ga in SS12

Inverse of LML SR is LML SKN. We get the value of LML SKN by subtracting 2 from modulo value 12.

∴ skn(sa) = kni.

∴ 12 - 2 = 10, this is *swara* kni in SS12 As a result

∴ skn(re) = sa and so on.

∴ (12 +2) = 14- 2 = 12 = 0, this is *swara* sa in SS12

LML SKR *(Shadja-Komal Rishabha Bhava):*

This is known as *Shadja-Komal Rishabha Bhava* in Indian music. For the modular processing if you add number 1 to any member of the set $SS12_m$ then you get the resultant member that is consonant with the original *swara* by the *Shadja-Komal Rishabha Bhava*.

∴ skr(sa) = kre.

∴ 0 + 1 = 1, this is *swara* kre in SS12

As a result

∴ skr(re) = kga and so on.

∴ 2 + 1 = 3, this is *swara* kga in SS12

Inverse of LML SKR is LML SN. We get value of LML SN by subtracting 1 from modulo value 12.

∴ sn(sa) = ni.

∴ 12 - 1 = 11, this is *swara* ni in SS12

As a result

∴ sn(re) = kre and so on.

∴ (12 +2) = 14- 1 = 13 = 1, this is *swara* kre in SS12It is evident that from the basic laws of musical logic rest of the laws can be derived. There exists a systemic consistency among all the laws of musical logic. Thus, the first set of LML is complete here. LML SKG, LML SR, LML SKR, LML SD, LML SKD, LML SN and LML SKN are not very strong by nature and therefore, generally, they are not recognized as the laws of consonance. Instead, LML SR, LML SKR, LML SN and LML SKN are considered the laws of dissonance in the traditional literature. Music needs consonance as well as dissonance. In a musical performance, an aesthetic tension is created using dissonance and then it is resolved by using consonance. Therefore, all the above-mentioned laws of musical logic are important.

Law of Musical Co-Existence of *Swaras* (LMCX)

LMCX is considered the law of the co-existence of *swaras* in the GTIM. It is observed that certain pairs of *swaras* always co-exist in *Ragas* and *Raga* rendering. This association of certain *swaras* is based on the LML SP and LML SM in most cases. From the set SS12 it is possible to generate all such pairs of *swaras* that adhere to LML SP. In reference to the following versions of SS12, it is shown how these pairs are generated.

SS12 = {sa, kre, re, kga, ga, ma, mat, pa, kdha, dha, kni, ni}

$SS12_m$ = {0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11}

SS12 with modular values = {sa (0), kre (1), re (2), kga (3), ga (4), ma (5), mat (6), pa (7), kdha (8), dha (9), kni (10), ni (11)}

sp(sa) = pa.

∴ 0 + 7 = 7, this is *swara* pa in SS12 so we get the pair <sa, pa>

sp(kre) = kdha.

∴ 1 + 7 = 8, this is *swara* kdha in SS12 so we get the pair <kre, kdha>

sp(re) = dha.

∴ 2 + 7 = 9, this is *swara* dha in SS12 so we get the pair <re, dha>

sp(kga) = kni.

∴ 3 + 7 = 10, this is *swara* kni in SS12 so we get the pair <kga, kni>

sp(ga) = ni.

∴ 4 + 7 = 11, this is *swara* ni SS12 so we get the pair <ga, ni>

sp(ma) = sa.

∴ 5 + 7 = 12=0, this is *swara* sa in SS12 so we get the pair <ma, sa>

sp(mat) = kre.

∴ 6 + 7 = 13=1, this is *swara* kre in SS12 so we get the pair <mat, kre>

sp(pa) = re.

∴ 7+ 7 = 14=2, this is *swara* re in SS12 so we get the pair <pa, re>

sp(kdha) = kga.

∴ 8+ 7 = 15=3, this is *swara* kga in SS12 so we get the pair <kdha, kga>

sp(dha) = ga.

∴ 9+ 7 = 16=4, this is *swara* ga in SS12 so we get the pair <dha, ga>

sp(kni) = ma.

∴ 10+ 7 = 17=5, this is *swara* ma in SS12 so we get the pair <kni, ma>

sp(ni) = mat.

∴ 11+ 7 = 18=6, this is *swara* mat in SS12 so we get the pair <ni, mat>

By applying the LML SP to all the members of the set SS12 we get a set of pairs of *swaras* that are very important. These pairs of *swaras* are very useful in the *Raga* generation process as well as the *Raga* rendering process. Each member in the pair necessitates the presence of the other member in a *Raga*. It is known that many *Ragas* have two *swara* forms of the same *swara* such as ma and mat. This rule contributes to generating such dual forms of *swaras* in a *Raga*. While *Raga* rendering these pairs are useful because these pairs are nothing but the *Meend swara* pairs. These LMCX co-*swara* pairs are as follows.

<sa, pa>, <kre, kdha>, <re, dha>, <kga, kni>, <ga, ni>, <ma, sa>, <mat, kre>, <pa, re>, <kdha, kga>, <dha, ga>, <kni, ma>, <ni, mat>.

By application of LML SG, similar pairs can be generated but it is found that they are useful for smaller *Meends* and they do not mandatorily necessitate the existence of their co-*swaras* therefore their application is very limited. So, such pairs are not covered under the law of LMCX.

Law of Harmonic Strength of *Swaras* (LHS)

Natyashastra mentions a concept of '*Balavatta*' of *swaras*, i.e., the strength of *swaras* or 'S*wara-Bala*' [Brihaspati, 1986, p. 110] though the words '*Balavad*' (possessing strength) and '*Abalata*' (weakness) are used, it is not elaborately discussed there. The Sanskrit word '*Bala*' means force or strength. Each *swara* in music has its own musical significance and inherent strength. The *Shadja swara* is very strong in Indian music and stands out in the *Raga* rendering. Similarly, other *swaras* have their individual aural or musical strength. The following paragraphs attempt to develop a hierarchical system of *swaras* based on their strength that is useful in Indian music.

Swaras/ shrutis can be divided into various categories based on their natural aural strength and accordingly ranks are assigned to them. There is a certain assumption behind this ranking. This ranking is not based on the frequency or the repeatability of *swaras* in musical rendering. This ranking is based on how a particular *swara/ shruti* stands out in a musical rendering on its own due to inherent harmonic strength. In most of the classical performances *Tanapura,* an Indian drone instrument, is placed in the background of the performers to provide musical context as well as generate musical aura, musical ambience or a spectrum of *swaras/ shrutis* as a referential context for performers. Typically, *swaras* played on *Tanapura* are sa, and pa to generate an effect of a drone. Therefore, there exists an abundance of *swara* sa and pa and their harmonics. In this ambience of a sa-pa drone when a performer performs, the *swara* sa and pa, being always present as a reference *swaras,* lose their significance being omnipresent. In such a case *swaras* other than sa and pa stand out in relative terms. However, *swaras* pa, and ma are used abundantly and frequently for *Nyasa* in a *Raga* rendering. Therefore, they somehow retain their significant unique positions. It is found that all the *swaras/ shrutis* can be divided into various groups in terms of their relative strength of standing out in the referential context. This grouping is discussed as follows.

The First Group

It is known that the ambience created by sa and pa *swaras* is very strong in the *Tanapura* context or even otherwise. Pa is the natural consonant *swara* of sa. Sometimes *Tanapura* is also tuned into sa-ma relationships. Ma is supposed to be the second consonant *swara* of sa. In that case, ma can replace pa but still, the presence of pa *swara* is somehow (due to natural harmonics) felt. It also means that even though pa is absent, its presence is prevalent. Therefore, it can be said that the strongest group of *swaras* is made up of sa, pa and ma. Their overall strength reduces in the same order as ‘sa’ > ‘pa’ > ‘ma’. In the overall order of all the *swaras* in terms of strength, this sequence is considered the strongest set of *swaras*.

In the overall order, *Shuddha Shadja* tops the hierarchy being the tonic of an octave and has a significant presence in the musical rendering though due to its omnipresence in the *Tanapura* drone, its strength has reduced to some extent, still *swara* sa remains the strongest *swara* in the octave. In this group, *Shuddha Panchama* finds a second place because as already mentioned it is the prime consonant of sa but because of over prevalence in the *Tanapura* ambience its harmonic strength reduces but still as already mentioned its strength remains intact. *Shuddha Madhyama* is the next in ranking. Like *Panchama* this also has omnipresence and in the absence of *Panchama,* it fills up the gap. It is almost equivalent to *Panchama* in terms of harmonic strength.

However, there exists a peculiar phenomenon. If there is a comparison among only these three *swaras*, namely, Sa, Pa and Ma, then the order is changed. *Swara* Sa is relatively less strong than the rest of the two *swaras*. So, this order changes to ‘pa’ > ‘ma’ > ‘sa’. Typically, this happens in the case of Sa as a *Vadi swara* and *Pa as a Samvadi swara*. If Sa is a *Vadi* in the *Raga,* then due to the omnipresence of sa *swara* in the *Tanapura* ambience, Sa as a *Vadi* does not have an impact and *Samvadi Pa* starts dominating. Pa *swara* starts playing the role of a *Vadi swara*. So, for choosing the *Ragas* having *Vadi-Samvadi* pairs from sa-pa, sa-ma, pa- sa, and ma-sa; only *Ragas* having pa-sa and ma-sa pairs turn out to be stronger in the *Tanapura* ambience. Other *Ragas* with *Vadi-Samvadi* pairs, sa-pa and sa-ma can be effective if there is no *Tanapura* ambience. But in general, the sa> pa> ma sequence comprises the strongest order of *swaras* and forms the first group of *swaras* in the hierarchy of strength.

The Second Group

The second strongest *swara* group is of - ‘ga’, ‘re’, ‘kga’, ‘kre’ *swaras*. These are the *Poorvanga swaras* since they belong to the first half of the octave. Thus, *shuddha Gandhar, shuddha Rishabha,* in the *Saptaka* with their *Komal* versions become the most important *swaras* in this group. Their strength is in decreasing order as ga > re > kga> kre. The flat versions follow the original *swaras* in terms of strength. Being flat/ *Komala,* their emotional appeal is very strong which brings in chromatic flavours in musical renderings. However, the individual harmonic strength of flat *swaras* is slightly less than its counterparts. The flat *swaras* due to this quality are considered special *swaras* and find a place in this group. *Poorvanga swaras* also provide foundations to the *Uttaranga swaras* and therefore, they are important. The significance of important *swaras* in this group in their ranking is elaborated as follows:

Shuddha Ga: Shuddha Gandhara is the strongest *swara* in this group by having consonant harmonics and also being the `*Swayambhu Gandhara*’.

Shuddha Re: By virtue of being the *Panchama of Panchama* this *swara* stands out quite prominently in the *Saptaka*.

Komal Gandhara KGa: *Komal Gandhara* is highly emotive and has second-level consonance with *Shadja* as well as *Panchama*. This relationship of ga with sa and pa respectively brings in special flavour in many *Ragas*.

Komal Rishabha KRe: This has second-level consonance with *Madhyama swara* and a special consonance with *Panchama*.

The Third Group

The third strongest group of *swaras* is made up of ‘dha’, ‘kdha’, ‘ni’, ‘kni’, ‘mat’ *swaras*. *Shuddha swaras* viz. *shuddha Dhaivata,* and *Komal Dhaivata* are the most important *swaras* in this group. Their strength is in decreasing order as dha > kdha > ni > kni > mat. However, the individual harmonic strength of these *swaras* is slightly less than the previous group i.e., the second group. *Teevra Madhyama swara* is very interesting. It is located between *Madhyama* and *Panchama* and is a geometric mean of these *swaras*. However, it is sort of sandwiched and therefore, it does not have much harmonic strength but emotionally it has maximum appeal. This is the last ranked *swara* in the top twelve *swaras* of the *Saptaka*. The significance of important *swaras* in this group in their ranking is elaborated as follows:

Shuddha Dha: Shuddha Dhaivata happens to be the most prominent *swara* of the `*Uttaranga*'- the second half of the octave and plays the role of *swara* Re in the *Uttaranga* rendering.

Komal Dhaivata (kdha): Most of the time this *swara* plays the role of *Komal Rishabha* in *Uttaranga* of the octave. This also has a second-level consonance with *Madhyama*.

Swaras such as *Shuddha Nishada* (ni), *Komala Nishada* (kni), and the *Teevra Madhyama* (mat) are the weakest *swaras* from the point of view of their harmonic strength. All the variations of *Nishada swara* are harmonically very weak though their chromatic flavours are high in appeal. They are placed in this group due to their harmonic weakness and chromatic strength. The *Teevra Madhyama* is a wonderful *swara* in terms of its emotional impact but since placed between *Shuddha Madhyama* and *Shuddha Panchama*, harmonically it is not considered consonant with *Shadja*. Interestingly, research and analysis of existing *Ragas* show and suggest that these three *swaras*- Ni, KNi, and Mat from this group are not considered worth becoming *Vadi* of a *Raga* in the prevalent Indian music. There is not a single *Raga* in Indian music that has a Ni, KNi or Mat as a *Vadi swara*. However, during Bharata Muni's times, Bharata Muni's *Nishada* had the status of a *Vadi swara* as well as *Amsha swara* of a *Naishadi Jati*. But today they have lost their status as a *Vadi swara* due to their inherent harmonic weakness.

The Fourth Group

The fourth strongest group is made up of Bharata Muni's *swaras*- 'bga', 'bre', 'bdha', 'bni'. Their strength is in decreasing order. Being extra flat/ *ati-komal*, their emotional appeal is very strong which brings in chromatic flavours in musical renderings. However, the individual harmonic strength of these *swaras* is slightly less than the previous group. Being flatter versions these *swaras* are part of Bharata Muni's octave and have extra chromatic flavours. Due to this quality, these are considered special *swaras* and find a place in this group of the fourth strongest *swaras* though they are extra flat. These do not find a place in standard twelve-tone contemporary *Saptaka*.

Bharata Muni's *Gandhara* (bga): Bharata's *Gandhara* is highly emotional and brings in great pathos in combination with *Komal Gandhara* and *Shuddha Gandhara*. But this *swara* is not used frequently. A well-known example of its use is from the *Raga Lagan Gandhara*.

Bharata Muni's *Rishabha* (bre): Bharata's *Rishabha* comes in various flavours in *Raga* rendering and is highly emotive and quite frequently used along with *Komal Rishbha* in *Raga* rendering.

Bharata Muni's *Dhaivata* (bdha): This *swara* plays the same role as Bharata Muni's *Rishabha* in *Uttaranga* of the octave.

During Bharata Muni's times, all the Bharata Muni's *swaras*- BGa, BRe, BDha, and BNI had a status of a *Vadi swara* as well as *Amsha swara*. It is worth exploring the possibility of making these *swaras* from this group as *Vadi swaras*. This may result in the revival of Bharata Muni's *Jati* system. However, presently the GTIM theory has not considered these *swaras* as important *swaras*.

The Fifth Group

The last group is made up of all the '*Chyuta*' *swaras*. Interestingly their ranking echoes the ranking of their *Shuddha* counterpart *swaras* established in previous groups. The group is made up of *Chyuta Shadja* ('csa') – rank 17, *Chyuta Panchama* ('cpa') – rank 18, *Chyuta Madhyama* ('cma') – rank 19, *Chyuta Komal Rishabha* ('ckre') – rank 20, *Chyuta Komal Dhaivata* ('ckdha') – rank 21, and finally *Chyuta Teevra Madhyama* ('cmat') – rank 22. All the *Chyuta swaras* are harmonically weakest in the context of an octave and therefore they are placed in this group. Apart from that their chromatic flavours are the least explored and not appear to be making any significant impact in contemporary Indian music. Still, they can contribute to a musical rendering. All these *swaras* are not part of the contemporary popular scale ET-12. They are inherited from Bharata Muni's system of ET-22 *shrutis*. Their potential application in musical rendering needs to be explored further.

Hierarchical Ranking of *Swaras/ Shrutis*

Thus, the overall ranking of *swara / shrutis* in terms of their harmonic strength is as follows.

=======***Nitya Swaras***======

Shuddha Shadja (sa) – rank 1

Shuddha Panchama (pa) – rank 2

Shuddha Madhyama (ma) – rank 3

======***Poorvanga Swaras***=====

Shuddha Gandhara (ga) – rank 4

Shuddha Rishabha (re) – rank 5

Komala Gandhara (kga) – rank 6

Komal Rishabha (kre) – rank 7

=======***Uttaranga Swaras***======

Shuddha Dhaivata (dha) – rank 8

Komala Dhaivata (kdha) – rank 9

Shuddha Nishada (ni) – rank 10

Komala Nishada (kni) – rank 11

Teevra Madhyama (mat) – rank 12

=======**Bharata Muni's *Swaras***======

Bharata Muni's *Gandhara* (bga) - rank 13

Bharata Muni's *Rishabha* (bre) - rank 14

Bharata Muni's *Dhaivata* (bdha) – rank 15

Bharata Muni's *Nishada* (bni) – rank 16

========***Chyuta Swaras***=======

Chyuta Shadja (csa) – rank 17

Chyuta Panchama (cpa) – rank 18

Chyuta Madhyama (cma) – rank 19

Chyuta Komal Rishabha (ckre) – rank 20

Chyuta Komal Dhaivata (ckdha) – rank 21

Chyuta Teevra Madhyama (cmat) – rank 22.

Thus, the ranking of all the 22 *shrutis* is complete here.

The law of harmonic strength has a basis in the harmonic strength of each member of the set SS12. Computational analysis in the context of *Raga* music suggests that certain *swaras* make a strong musical impact. A hierarchy of such *swaras* is generated through computational explorations of *swaras* in various *Ragas*. It is also interesting to know that there is some correlation between the hierarchy of the above-mentioned LMLs and this hierarchy of *swaras*. If we apply these LMLs to the basic scale of SS12 then the order of the LMLs can be consistently mapped with the harmonic hierarchy of *swaras*. There are a few minor deviations though. The harmonic hierarchy of *swaras* is as follows. The strongest member of the SS12 based in this hierarchy is kept on the left of the symbol '>' showing the relations. So, the left-most *swara* is the strongest *swara* while the right-most *swara* is the weakest *swara* in the following order. Initially order for the commonly used 12 *swaras* is given as follows because our main domain of description is SS12.

sa > pa > ma > ga > re > kga > kre > dha > kdha > ni > kni > mat

The order for Bharata Muni's *swaras* combined with the *Chyuta swaras* is as follows.

mat > bga > bre > bdha > bni > csa > cpa > cma > cre > cdha > cmat

The *swara* sa is the strongest and the *swara* mat is the weakest in SS12. This order helps in deciding the main *Samvadi swara*, primary *Anuvadi swaras*, and primary *Anu- Anuvadi swaras*, and also helps in characterizing *Nitya swaras*, and the status of many other *swaras* in the *Raga* generation process and *Raga* rendering process. Therefore, this law has a special place in the generative dynamics of *Ragas*. This hierarchy is at the core of GTIM.

Law of *Nitya Swaras* (LNS)

Sa, Pa, and Ma are called *'Nitya' swaras* in GTIM. They have a seminal role in the *Raga* generation process as well as the *Raga* rendering processes. Based on the law of harmonic ranking 'sa', 'pa' and 'ma' *swaras* have the highest ranking as first, second, and third rank respectively. Due to their extraordinary harmonic strength, these *swaras* have dominance and prevalence in *Raga* rendering processes. The harmonic context generated by *Tanapura* is one of the major reasons these *swaras* are called *Nitya swaras*. Because of the repeated plucking of *Tanapura*, these *swaras* become stronger and anchored but 'over-presence' makes them banal and neutral too. Due to these characteristics, *Nitya swaras* have a dual role to play. As they are neutral their role as a *Vadi* becomes secondary and they do not shine forth as *Vadi swaras*. However, since they are strong and anchored due to their omnipresence, they become a resting point in *Raga* rendering and are called *Nitya Nyasa swaras*. As they are anchored firmly, they are also used as launching pads for starting a *swara* phrase and so they are considered as default take-off *swaras* or *Nitya Graha swaras*.

Nitya swaras attain their status because they are the prominent *swaras* of the foundational scale. In a musical performance, the *Tanapura* provides the harmonic context and *swaras* 'sa', and 'pa'/ 'ma' are being played repeatedly on the strings of the *Tanapura*. For the audience, from a psycho-acoustic point of view, this provides the harmonic base against which all the *swaras* of the *Raga* are compared, related and perceived. This base scale provides the basis for musical and aesthetic appreciation of the *Raga*. Since *swara* 'sa' is constantly played on the *Tanapura*, it is abundant in the environment. Due to this abundance of 'sa', interestingly it becomes a neutral *swara*. Similarly, 'pa' is also abundant and becomes neutral *swara*. If 'ma' is played on the *Tanapura* then 'ma' also becomes abundant and becomes neutral. The Neutrality of'sa', 'pa' and'ma' is important because it provides a tuning context and scalar foundations to the musical performance. As '0' (zero) is a neutral number and plays an important role in a mathematical context, similarly, *swara* 'sa' is a neutral *swara* and plays an equally important role in music. 'Sa' being a tonic is the most neutral *swara*. 'Pa' is less neutral than 'sa' while 'ma' is even less neutral from a musical point of view. This needs some explanation. When *Tanapura* provides harmonic context and the atmosphere is pervaded by 'sa', 'pa' and optionally by 'ma' *swaras* a musical common base is created. As a performer starts rendering a Raga, the audience tries to relate and contextualize the *swara* phrases of a *Raga* by referring to this context. The audience appreciates the rendering of *swaras* and *swara*-phrases if they significantly stand out against this context. The role of the *Vadi swara, Samvadi swara, Anuvadi swara* and *Anu-Anuvadi swaras* of the *Raga* and their phrases with *alaaps* (free and aesthetic exposition of notes) and '*gamaka*' (oscillations on notes) becomes important to make the *Raga* rendering appealing to the audience. This creates musically necessary aesthetic tension.

Raga rendering is nothing but generation and explorations of such musically significant aesthetic tension. When a performer wants to release the tension and relax, the performer will rest on the *Nyasa swaras* which are in most cases 'sa' and 'pa' *swaras*. 'Sa' and 'pa' are thus permanent resting *swaras*. In this sense, they are called *Nitya swaras*. There are many such functions of 'sa', 'pa' and 'ma' *swaras* that make them neutral *swaras*. As a result of this phenomenon, when 'sa', 'pa' or 'ma' is a *Vadi* of the *Raga* they do not contribute significantly to the '*Raganess*' of the *Raga*.

So, the set of *Nitya swaras* may be represented as follows.

Nitya Swaras = {'sa', 'pa', 'ma'}

As already mentioned during the discussion on the law of harmonic strength of *swaras* (LHS) Sa is the strongest *swara* as far as the harmonic strength of *swaras* is concerned. But as it is being discussed *Nitya swaras* are also neutral *swaras* in certain contexts. As a general rule, *Nitya swaras* are stronger than all the other *swaras* or *shrutis* as far as harmonic strength is concerned. But when there is competition between and among the *Nitya swaras* then the order of strength changes slightly due to the over prevalence of Sa *swara* in the *Tanapura* harmonic context. In such a situation the order of harmonic strength of *Nitya swaras* is as follows.

'pa' > 'ma' > 'sa'

This order may be termed as the Law of Harmonic Strength for *Nitya swaras* (LHS*Nitya*)

Law of Emotive *Swaras* (LES)

This law can be described as a law of dissonance. As there are laws of musical consonances as discussed in earlier paragraphs, there exists a certain relationship between *swaras* that are dissonant to each other. If two *swaras* have a semitonal relationship then these two *swaras* happen to be dissonant to each other. In Bharata Muni's ET-22 scale, there exist even quarter-tone relationships as well. The semitonal relationship is called the '*Vivadi*' *swara* relationship in Bharata Muni's scale. Dissonance is the opposite of consonance but contrary to the general understanding of dissonance, it contributes to enhancing aesthetic experience. Dissonance helps in building aesthetic tension. The musical phrase that uses semitonal and quarter tonal *swaras* is responsible for such tension. Tension also leads to emotional evocation which is very significant from the aesthetic point of view. Therefore, dissonance helps in building the mood of the *Raga*. Generally, the flat notes or *Komal swaras* have semitonal or in some cases quarter tone relationship with their respective pure notes or *Shuddha swaras*. Therefore, in this sense flat *swaras* are called semitonal or chromatic *swaras*. The semitone *swaras* or the chromatic *swaras* in a *Saptaka* bring emotional flavour to the *Raga*. These are- 'kre', 'kga', 'mat', 'kdha', and 'kni'. Along with them, their other microtonal variations play a very important role in creating and augmenting the mood of the *Raga*. These *swaras* are mostly from Bharat Muni's *Saptaka*- 'bre', 'bga', 'bdha' and 'bni'. *Swaras* like 'cmat', 'cma' and 'csa' also contribute in a significant way.

Thus, the description of the laws of musical logic (LMI) concludes here. During the discussion the laws of musical logic (LMLs), law of musical co-existence of swaras (LMCX), law of harmonic strength (LHS), law of *Nitya swaras* (LNS), law of harmonic strength for *Nitya swaras* (LHS*Nitya*), law of emotive swaras (LES) were discussed in details so that logical foundations of the GTIM system become stronger.

The previous chapter and this chapter characterized two important entities of the GTIM- a set of basic elements and a set of the laws of musical logic that operate on this set. These two sets form the core of the GTIM. With these fundamentals in place, it will be easier to develop the GTIM further in the next few chapters.

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PART IV
Defining *Raga* (Ma)

CHAPTER 10

Characterizing *Raga*

Introduction

India has a long tradition of music encoded in *Naradiya Shiksha*, *Natyashastra* and *Sangita Ratnakar* and many other treatises on Indian music. First systematic reference to the term *Raga* comes in Matanga Muni's *Brihaddeshi* [Sharma, Prema Lata, 1994]. We find a good deal of discussion on *Raga* in this treatise in a highly structured manner. The *Raga* system was not there during the age of Bharat Muni's *Natyashastra*. There was a *Jati* system. It is believed that the *Raga* system has evolved from the *Jati* system. *Natyashastra* describes the ten *Lakshanas* of *Jati*. These are *Amsha* (important note), *Graha* (starting note), *Taara* (higher note), *Mandra* (lower note), *Nyasa* (resting note), *Apanyasa* (short-resting note), *Alpatva* (least used note), *Bahutva* (most used note), *Shadava* (*Raga* with 6 notes) and *Oudava* (*Raga* with 5 notes). It may be argued that these ten *Lakshanas* or features of *Jati* are very much applicable to *Raga*. On that basis, it can be said that *Ragas* have evolved from *Jatis*. It is believed that *Ragas* have evolved from *Jatis* by making changes or modifications in the features of *Jatis*. It is possible to trace the trajectory of the evolution of the concept of *Raga* from the earlier *Jati* system. There is a truism in this belief. The GTIM accepts the historical evolution but at the same time attempts to unearth the underlying formal musical logic of these historical developments. The codified musical knowledge preserved in the above-mentioned treatises provides a strong framework to establish the hidden logical trajectories.

However, during the medieval age and the last few centuries, this codified knowledge was either lost or incomprehensible for the practitioners of Indian music. In the last few centuries, the tradition has preserved the musical practices but the knowledge behind these practices remained a mystery or a secret. The traditional knowledge of music is supposed to be embodied in contemporary musical practices and from these practices, we need to connect the dots and relate it to the earlier codified concepts from the afore-mentioned treatises. The codified knowledge was always present implicitly in the practice but somehow was never explicitly articulated. Overall, in India, music has been a vocal or non-written musical practice, a sort of oral tradition. Therefore, even contemporary practitioners carry a large chunk of such knowledge which is canonical in nature. At times it is in the instructive form mentioning certain types of usage of certain *swaras* in a particular *Raga*. Sometimes we find a description of *Ragas* mentioning what type of *swara* usage is allowed in the *Raga* and what kind of *swara* usage is not allowed in the *Raga*. In this sense, the existing musical knowledge carried by the practitioners of music is prescriptive in nature. What is not available is the robust theoretical structure behind the musical practices. Musicians carry deep insights about music but these are not articulated systematically. What is required is the logical connect between the current practices and the codified knowledge of ancient treatises. Pandit Venkatamakhin and Pandit Bhatkhande attempted to bridge this gap. Their contribution in this regard is historically magnificent. But there is a need to take it forward and make this connection between practice and theory more formidable.

Brihaddeshi written by Matanga Muni, for instance, gives a definition of *Raga* that enlists ten features of a *Raga* mostly based on the ancient treatises and taking into consideration then prevalent practices in Indian music. *Raga* is a significant arrangement of sounds and it is ornamented by *Swaras* and *Varnas* (phrases) that are *Sthayi* (Stable), Arohi (Ascending), Avrohi (Descending) and Sanchari (Moving in ascending as well as descending directions) movements of *swaras*, that entertains the audience. This is the original characterization of *Raga* by Matanga Muni, Pandit Bhatkhande improvised on this. The ten features of a *Raga* identified by Pandit Bhatkhande are as follows. Accordingly, a *Raga* should originate from a class called *Thaata*. The *Thaata* is a concept developed by Pandit Bhatkhande by taking inspiration from the concept of '*Mela*' developed by Pandit Venkatamakhin. *Raga* is a significant arrangement of sounds. It is decorated with *swaras* and *Varnas*. It should be beautiful. There should be at least five *swaras* in a *Raga*. Two forms of the same *swara* should not come consecutively while rendering a *Raga*. There should be an *Aroha*- ascending and *Avroha*- descending arrangement of *swaras*. *Shadja swara* should not be eliminated from the *Raga*. A *Raga* should have at least *Madhyama* and/ or *Panchama* as a member of the *Raga*. *Raga* should have *Vadi* and *Samvadi swaras*. Later on, in his writings, Pandit Bhatkhande added a few more features to his earlier understanding of *Raga*. These are *Pakad* or 'catchphrase of a *Raga*', *Poorvanga* (first half of the octave) domination and *Uttaranga* (latter half of the octave) domination of a *Raga*, Time of the *Raga*- morning *Ragas*, twilight *Ragas*, evening *Ragas* etc., *Rasa*, *Aavirbhava* (original mood the raga) and *Tirobhava* (suggestive of another raga) of the *Raga*. In a *Raga* rendering when phrases of similar *Ragas* are taken to generate an element of surprise, it is called *Tirobhava* and then again when the phrases of original *Ragas* are rendered it is called *Aavirbhava* of the original *Raga*. All these features are identified and co-related with the similar concepts from ancient treatises. These efforts are highly fulfilling and provide a better understanding of the concept of *Raga*. [Bhatkhande V. N., 1998 second edition]. Pandit Bhatkhande had already started the process of systemizing and characterizing *Ragas*. Looking at the contemporary developments in information technology there is a need of connecting these concepts with ancient treatises and redefining these concepts from a musical, academic and logical point of view. This exercise will unfold more robust theoretical foundations for Indian music at large and the concept of *Raga* in particular.

The term *Raga* is more specific to the domain of music and that too Indian music. *Natyashastra* defines music as *Gandharvam* which has three facets- *Swara, Tala*, and *Pada*. The term *Gandharvam* is synonymous with music at large and out of these three facets *Swara* aspect of music is more relevant to the concept of *Raga*. *Tala* and *Pada* are necessary components of a *Raga* performance but even without *Tala* and *Pada* a *Raga* can be rendered. Therefore, it is more appropriate to delimit the term *Raga* to the *Swara* dimension of *Gandharvam* or music. Elaborately rendered *Aalaps* of a *Raga* do qualify as an entertaining piece of music. Rhythmic patterns of *Tala* and poetic words or *Padas* certainly enhance the beauty of a *Raga* and the entertaining quality of a *Raga*. However, rhythmic patterns or poetic words alone are never considered a *Raga* though they might entertain the audience. It is more appropriate and logical to focus on the *swara* dimension of *Gandharvam* or music for defining or characterizing a *Raga*. From an academic and musical perspective, the term *Raga* needs to be defined considering *Swara* as the sole denominator.

The traditional definitions of *Raga* or the way *Raga* is characterized by practising musicians are not sufficient to develop a computational theory of *Raga*. There is a need for a more rigorous characterization of the notion of *Raga*.

Raga defining Characteristics

Historically musical systems in India have evolved from earlier *Rigvedic* and *Samavedic* recitations that used only three *swaras*. Therefore, *Udatta, Anudatta* and *Swarita swaras* are at the core of Bharata's octave and eventually reflected in further developments of Indian music that include the development of *Raga* music. The *Samvadi swara* became important later on to provide anchoring in the other half of the octave when the three Vedic *swaras* were extended into pentatonic tunes using five *swaras*. From five *swara* melodies/ *Ragas* then evolved into six *swara*, and seven *swara* melodies/ *Ragas* and later on even using up to nine *swaras*. The same evolutionary process reflects in the structure and character of modern-day *Ragas*. This process can ideally be used by applying principles of computational/ aural logic for the generation of *Ragas* in GTIM. However, it is expensive in terms of processing time, computer memory and processing speed from a computational point of view. To save on computational resources, in *AI-Raga*, an algorithm is developed that initially generates all possible seven-*swara Ragas* having *Vadi, Samvadi* (and *Anya Samvadi*), two *Anuvadis* and two *Anu-Anuvadis* that have a seminal role in *Raga*. After conducting computational simulations and their analysis of several known *Ragas* the author has arrived at these conclusions. It is explained as follows.

Each *Raga* has one *Vadi swara*, one main *Samvadi swara* and optionally one *Anya*

Samvadi swara. Sometimes in *Shadava* or *Oudava Ragas,* this *Anya Samvadi* is not there. A *Raga* also has one primary *Anuvadi swara* and one secondary *Anuvadi swara*. The inclusion of the secondary *Anuvadi swara* is optional. Apart from this, a *Raga* has two *Anu-Anuvadi swaras*. Both are equally important in the *Raga*, however, harmonically stronger between them becomes the primary *Anu-Anuvadi*, the proverbial first among the equals. In *Shadava* and *Oudava Ragas* there exists only one *Anu-Anuvadi swara*.

Important characteristics of a *Raga* may be defined as follows. The following description will pave the way to the formal definition of *Raga*. *Vadi swara*, *Samvadi swaras*, *Anuvadi swaras* and *Anu-Anuvadi swaras* are the *Raga*-defining *swaras* in a *Raga*. They are like the building blocks of a *Raga*. In a *Raga,* there has to be a *Vadi* or a dominant *swara*. *Vadi* cannot be eliminated from the *Raga* since it is the *Raga* defining *swara*. A *Raga* should have at least one *Samvadi swara* that is derived by applying *Shadja-Panchama Bhava* or *Shadja-Madhyam Bhava* to the *Vadi swara*. Thus, if *Vadi swara* is in the *Poorvanga* of a *Saptaka* then the *Samvadi* will be in the *Uttaranga* of the *Saptaka* and vice-versa. A *Raga* can have two *Samvadi swaras* but the stronger between them will become the primary *Samvadi* and the other *swara* is called *Anya Samvadi* or just *Anya swara*. The strength of a *swara* is decided by the laws of musical logic as discussed earlier. The strength of the *Samvadi* is decided by three laws to be more specific. The first is the law of *Nitya swaras*, the second is the law of harmonic strength and the third is the law of co-existence of *swaras*. These laws are already introduced in previous chapters. However, for deciding the primacy of *Samvadi swara*, first, the law of *Nitya swaras* is to be applied. If it is not applicable then the law of co-existence of *swaras* is to be applied. If it is not applicable then the law of harmonic strength is to be applied to decide the main *Samvadi swara* and the *Anya Samvadi swara*. For instance, if 're' is the *Vadi* of the *Raga* then it has two competing *Samvadi swaras* as 'dha' and 'pa'. Between the two of them the 'pa' is a *Nitya swara* and so naturally it is harmonically stronger and gets the status of the main *Samvadi swara* and 'dha' becomes the *Anya Samvadi* or just *Anya swara*. But if the *Vadi swara* is 'ga' then it has two competing *Samvadi swaras* as 'ni' and 'dha'. None of them is a *Nitya swara* so the law of *Nitya swara* is not applicable. The law of co-existence of *swara* is very much applicable here because there exists a 'ga'- 'ni' association. So whenever, 'ga' is there 'ni' has to be there by the law of co-existence of *swaras*. So, by the application of this law 'ni' becomes the main *Samvadi* and 'dha' becomes the *Anya swara* in this case. Interestingly here 'ni' is harmonically weaker than 'dha' but still 'ni' becomes the main *Samvadi* due to the strength of association between 'ga' and 'ni' *swaras*. If the *Vadi* of a *Raga* is 'dha' then it has two possible *Samvadi swaras* as 'ga' and 're'. Here the law of harmonic strength is applicable because the other two laws are not suitable. So naturally, 'ga' becomes the main *Samvadi* and 're' becomes the *Anya swara* because the harmonic strength of 'ga' is more than the harmonic strength of 're'.

Apart from *Samvadi swaras*, a *Raga* should have *Anuvadi swaras*. *Anuvadi* *swaras* are derived by applying *Shadja-Gandhara Bhava* and *Shadja-Komal Gandhara Bhava* to the *Vadi swara*. So there exist four possible *Anuvadi swaras*: two possible *Anuvadi swaras* when these two *Bhavas* are applied in ascending direction and two possible *Anuvadi swaras* when these two *Bhavas* are applied in descending direction. Now here also similar harmonic dynamics that are discussed in the case of *Samvadi swaras* will work while selecting the primacy of *Anuvadi swaras*. Out of four possible *Anuvadi swaras* two are selected by applying the same above-mentioned three laws. But there is one additional constraint- two *Anuvadis* that are selected should not be the '*swara*-forms' of each other. For instance, 'ga' and 'kga' cannot be selected as two *Anuvadis*. Due to this rule selected *Anuvadis* will never be on either ascending or descending side of the *Vadi swara*. Always one *Anuvadi swara* will be on the ascending side and the other will be on the descending side or vice-versa. Once two *Anuvadis* are selected the strongest one is called primary *Anuvadi* and the other one is called secondary *Anuvadi*. Henceforth, in all the following descriptions, primary *Anuvadi* is referred to as *PAnuvadi* and secondary *Anuvadi* is called *SAnuvadi*. In *Raga* rendering *PAnuvadi swara* is given a dominant role since it is considered the '*Bhava*' *swara* or the *swara* that brings in the emotions or the essential flavour to the *Raga*.

Similarly, two *Anu-Anuvadi swaras* are also selected. The only difference is that they are derived by applying *Shadja-Rishabha Bhava* and *Shadja-Komal Rishabha Bhava* in ascending and descending order to the *Vadi swara*. Both the *Anu- Anuvadi swaras* are close to the *Vadi swara* and help provide momentum to *Raga* rendering. The rest of the generative harmonic dynamics remains the same for selecting the primary *Anu-Anuvadi swara* and the secondary *Anu-Anuvadi swara*. The primary *Anu-Anuvadi* is called *PAnu-Anuvadi swara* and the secondary *Anu- Anuvadi swara* is called *SAnu-Anuvadi swara*. Both the *Anu-Anuvadi swara* has equal importance in rendering the *Raga* even though due to stronger harmonic strength the *PAnu-Anuvadi swara* shines forth and gives momentum to *Raga* rendering by being closer to the *Vadi swara*.

Formal Definition of *Raga*

This can be a good context to define and characterize the concept of *Raga* for theoretical purposes. This theorization, of course, has a strong computational dimension. Traditionally, a *Raga* is defined as an entity that entertains the minds of the audience. This being a quite broad definition, Matanga Muni during ancient times and Pandit Bhatkhande in modern times tried to define *Raga* more concretely. According to them, a *Raga* is a significant set of sounds that comprises *swaras* ornamented with *Varnas* and also that entertains the minds of the audience [Bhatkhande V. N., 1998 second edition]. Here *Varna* is a technical term. It has four aspects- *Sthayi, Aroha, Avroha* and *Sanchari*. The meaning of the term *Sthayi* is very specific. *Sthayi* means stable *swara*. *Aroha* means the ascending order of *swaras* in a *Saptaka* and *Avroha* means a descending order of *swaras*. *Sanchari* means the movement of *swaras* that could be consecutive in ascending order or it can be consecutive descending movement or there can be a movement from one *swara* to another by skipping in-between *swaras* or jumping from one *swara* to another *swara* without following any sequence. Similarly, *Sanchari* also means the movement can be a combination of ascending and descending patterns of *swaras*. *Natyashastra* uses the term '*Aantar-Marga*' for *Sanchari*. The term '*Antar-Marga*' can also be understood as a *Meend* or glide. All these descriptions can be formalized and represented rigorously. Now here we will describe the concept of a *Raga* in an abstract manner which is more compact and elegant.

Let us assume a *Raga* as an abstract musico-mathematical structure that has the components mentioned in the above paragraph. It is called musico-mathematical structure because the whole concepts from Indian music are presented and represented in a mathematical notation. However, this notation deviates from standard mathematical notation in certain cases but overall treatment is very similar to mathematical description.

Initially, as was discussed in earlier chapters while developing logical foundations of music, it is assumed that there exists a larger domain of all possible frequencies of sound called the domain MD. Out of this domain, a limited domain of musically significant frequencies can be extracted as the domain of musical context. With the help of *Tanapura,* it is easier to set such a contextual domain. This domain is named MCD- the domain of musical context. From MCD it is possible to identify a specific frequency as a base frequency as a tonic or *Aadhar Swara* called Sa or the *Shadja swara*. From the tonic it is possible to explore various options of formulating organized sets of twenty-two *shrutis* called ET22, sets of twelve *swaras* called ET12, SS12 and finally sets of seven *swaras* called SS7. As the next important step in the development of the logical and computational foundations of GTIM, it is necessary to develop a formal scheme for the description of a *Raga*.

Let us visualize an abstract musical structure called *SwaraO* representing the original generative entity from which the entire domain of *Raga* music originates. *SwaraO* is a subset of MCD. As already discussed, the base *swara* frequency and the generative set of aural, physical and psycho-acoustical laws of musical logic is inherently part of this structure.

SwaraO = {O}.

This may unfold into the following abstract structure *RagaO* as described below. Even other structures such as *Jatis* or Symphonies can be generated from *SwaraO* in principle. However, that is not the focus of the current description.

It is possible to envisage an abstract 2-tuple musical structure called *RagaO* denoting the essential original form or the 'pre-*Raga*' status that has one frequency and a set of generative rules to operate on it.

RagaO = {S, GL}

S is the base frequency Sa or the *Shadja swara* and GL (Generative Laws) stands for the laws for generating music. As discussed earlier, GL is the set of Generative Laws of musical logic and inherently exists in the base tonic *swara*

S. In this sense S and GL always co-exist and they are inseparable. A detailed description of the GL is given in the following sections. By applying these rules to S, a new set of entities called *Saptaka* is generated as described earlier in this book. The *Saptaka* can be represented in various ways, as discussed earlier. Bharata's *Saptaka* had seven *swaras* with equal-temperament 22 *shrutis* so it was termed as ET22 set. Currently, the popular *Saptaka* has equal-temperament 12 *swaras* so it is called ET12/ SS12. In the following description, SS12 is taken as the basis for description because it can accommodate multiple scaler possibilities. At times other representations of SS12 are also used for ease of understanding. As already discussed, the SS12 can be mapped on ET22 set representing Bharata Muni's *shrutis* as well as SS12 can be mapped on SS7 set that stands for a *Saptaka* of seven *swaras*. The structure *Raga* emerges out of *RagaO* at a very primordial level where it is assumed that the base entity S or Sa exists. A set of rules of aural and musical logic called GL exists and out of the interaction between S and GL a *Saptaka* SS12 or at times SS7 is generated. Against this setting, we can build the description of a *Raga*.

Raga Structure

Raga as a musico-mathematical structure is derivable from the above-mentioned abstract structure *RagaO*. It may be represented as a 6-tuple as follows.

Raga = {S, A, D, V, VRJL, GL}

Here the domain of the description is a set SS12 which is earlier discussed. It is assumed that the *swara* Sa is a default tonic *swara* of SS12. Therefore, S stands for Sa and it is mentioned especially in the description of the *Raga* structure. At times, Sa and V are the same where V stands for a *Vadi swara* however, Sa has a special identity as a tonic. The set of generative rules GL is included because it has an explicit role in various generative processes. Other entities in this tuple are described as follows. Each member of the tuple is unique in a musically significant way. *Samvadis, Anuvadis and Anu- Anuvadis* are not made part of this tuple because they are derivable from the *Vadi swara* by application of the laws of musical logic. *Varjya swara* list VRJL is a part of the description because these *swaras* are chosen by a norm and are not derivable by the laws of musical logic.

***Aroha*: '**A' stands for *Aroha*, a set of *swaras* used in a *Raga* in ascending order and the number of such *swaras* in a *Raga* should not be less than 5 and it should not exceed 7.

$\therefore A \subsetneq SS12, |A| \geq 5, |A| \leq 7$

Avroha**:** D stands for *Avroha*, a set of *swaras* used in a *Raga* in descending order and the number of such *swaras* should not be less than 5 and it should not exceed 7.

$\therefore$ D $\subsetneq$ SS12, $|D| \geq 5$, $|D| \leq 7$

A *Raga* may have all the 12 *swaras*, for example, *Raga Piloo* of North Indian style of music allows to use all the 12 *swaras* in its rendering. Similarly, there are a few rare *Ragas* that have only 4 *swaras* in it such as *Raga Bhavani*. But such examples are very rare. As a general rule, a *Raga* cannot have less than 5 *swaras* and normally the number of *swaras* in a *Raga* does not exceed more than 9 in *Aroha* or *Avroha*. It may be possible that some of the 9 *swaras* from the *Aroha* may not be there in the *Avroha* and vice versa. So as a general rule, a *Raga* cannot have less than 5 *swaras* and it does not have more than 9 *swaras* in *Aroha* or *Avroha*. This includes the dual forms of *swaras*. As far as the basic structure of a *Raga* is considered there should not be more than 7 *swaras* either in *Aroha* and/ or in *Avroha*. When such *swaras* are chosen care is taken that both the *swara* forms are not selected in the basic structure of the *Aroha* or *Avroha*. So as an example, if there exists *swara* ga in the *Aroha* of the *Raga* then the kga is not chosen as a member of the *Aroha*. But *Avroha* can have the *swara kga*. Two such instances can be allowed in the basic structure of the *Raga* but the number 7 is specified as a limit for the number of *swaras* in *Aroha* and *Avroha* as far as the basic structure of the *Raga* is concerned.

Vadi**:** v stands for a *Vadi swara* v is such that *Vadi* v is a member of A as well as D, it also means *Vadi* v cannot be a *Varjya swara* in the *Raga*.

$\therefore$ v $\in$ A and v $\in$ D or

$\therefore$ v $\in$ (A $\wedge$ D) or

$\therefore$ v $\in$ A $\wedge$ D

Varjya Swaras:

A set VRJ is included in the *Raga* structure because it is very important from a computational point of view. VRJ stands for a set of *Varjya swaras*. Sometimes one or two *swaras* are eliminated from a *Raga*.

$\therefore 0 \leq |VRJ| \leq 2$

The *Varjya swara* set comprises of maximum two *swaras* in *Aroha* and a maximum of two *swaras* in *Avroha*. Only in *Chatuswari Ragas* number of *Varjya swaras* can be three but such *Ragas* are not considered standard *Ragas*.

VRJ can be an empty set if there are no *Varjya swaras* in a *Raga*. For instance, the *Sampurna-Sampurna Ragas* do not have *Varjya swaras* either in *Aroha* or in *Avroha*.

$\therefore$ vrj $\notin$ A $\wedge$ D or

$\therefore$ VRJ = {∅}

but normally VRJ has two subsets, one for the *Aroha* and the other for *Avroha*. It may be represented as

$\therefore$ VRJ = {VRJA, VRJD} = {∅, ∅} but for the brevity of representation it is shown as VRJ = {∅} here.

Varjya swaras can be a *Varjya* from the *Aroha* alone so vrj $\notin$ A in the case of *Shadava-Sampurna Raga* will be shown as

VRJ= {{vrj1}, VRJD} = {VRJA, ∅} = {{vrj1}, ∅}

and for *Oudava-Sampurna Ragas* it will be

vrj1, vrj2 $\notin$ A so the VRJ= {{vrj1, vrj2}, VRJD} = {VRJA, ∅} = {{vrj1, vrj2}, ∅}

In some cases, it can be *Varjya* from the *Avroha* alone so vrj $\notin$ D, in all such cases representation of *Varjya swaras* can be done for *Sampurna-Shadava Ragas* and *Sampurna-Oudava Ragas* as shown above.

The important notions for characterizing a *Raga* are:

- *Vadi swara, Samvadi swara,* Primary *Anuvadi swara* (Secondary *Anuvadi swara*), Primary *Anu-Anuvadi swaras and* Secondary *Anu-Anuvadi swara.*
- *Varjya swaras, Ardha-Varjya swaras.*
- *Vakra swaras and Durbala* (*weak*) *swaras* and *Vivadi swaras*.

A Set of Generative Rules

GL: GL stands for all the possible laws or rules that contribute to generating and rendering *Raga*. This set of laws comprises of LMLs which are the laws of musical logic, LGP which are the rules for generating all types of musical phrases for *Raga* rendering along with certain allied rules and factors that contribute to rendering *Raga*. A brief description relevant to the formal characterization of all these laws is presented below. The detailed treatment of these laws is provided at appropriate places. LMLs are already discussed in detail in the chapter dedicated to these laws. LGP that is the laws for phrase generation will be discussed thoroughly in the chapter on phrase generation. Following is just a summary of the laws of musical logic.

LML: LML stands for laws of musical logic. In earlier chapters, there has been a good deal of discussion on these laws. Still in the context of the characterization of *Raga*, the laws of musical logic are briefly mentioned here again.

Laws of Musical Logic: Traditional Indian music is based on the laws of consonance. The first law is the law of *Swabhava* i.e., each *swara* is consonant to itself. The second law is the law of *Samabhava* i.e., each *swara* is consonant to its higher and lower versions in the higher and lower *Saptaka*. Then there are two main laws of consonance mentioned in the *Natyashastra* of Bharata Muni. They are called the laws of *Samvad Bhava*. These are called *Shadja-Panchama Bhava* and *Shadja-Madhyama Bhava*. Based on the same aural and musical logic few more laws of consonance can be derived. They are *Shadja-Gandhara Bhava, Shadja-Rishabha Bhava, Shadja-Komal Gandhara Bhava,* and *Shadja-Komal Rishabha Bhava*. The degree of consonance is decreasing in all these laws in the same order as mentioned above. Therefore, sometimes the last law is treated as the law of dissonance.

Law of Harmonic Strength: *Swaras* and *shrutis* are ranked as per their harmonic strength in the *Saptaka*. This law is a core fundamental principle of the entire Indian *Raga* system and therefore, these rankings of *swaras* and *shrutis* play a very important role in the *Raga* generation process. This is an important feature of GTIM and one of the major contributions of the author of this book.

Law of *Nitya swaras*: As a default, there exist the following types of *Nitya swaras* that contribute to the *Raga* generation process and the *Raga* rendering process. They are *Nitya Swaras, Nitya Graha swaras* and *Nitya Nyasa Swaras*. Based on the law of harmonic ranking 'sa', 'pa' and 'ma' *swaras* have the highest ranking as the first rank, second rank, and the third rank respectively. Due to their extraordinary harmonic strength, these *swaras* have dominance and prevalence in the *Raga* generation process as well as in the *Raga* rendering processes. This is an important set of *swaras*. The set of *Nitya swaras* has multiple roles. A set of [Sa, Pa, Ma] is called the set of *Nitya swaras*. All the members of this set are the default *Graha swaras* and *the Nyasa swaras* by default. Apart from this Sa can play the role of *Vadi, Samvadi, Anuvadi* or *Anu-Anuvadi* in the *Raga* rendering. *Swaras* Pa and Ma can play the role of *Samvadis* in the *Raga* rendering and therefore they are *Nitya Samvadi swaras*. Then there are special *Nitya Graha swaras* such as KNi, Ni, Ga, and KGa. It means if these swaras are the member of the *Raga* then they act as *Graha swaras* by default. Similarly, Sa and Pa are the *Nitya Nyasa swaras* for all *Ragas*.

Nitya swaras = {'sa', 'pa', 'ma'}.

Apart from the above set of *Nitya swaras,* there is a set of default *Nitya Graha swaras*, default *Nitya Nyasa swaras*, and default *Nitya Sama swaras* as shown below. They perform their roles as respective default *swaras* in the *Raga* generation process as well as the *Raga* rendering process.

Nitya Graha swaras= {'kga', 'ga', 'kni', 'ni', *Vadi, Samvadi*, 'sa', 'pa', 'ma'}.

Nitya Nyasa swaras= (*Vadi, Samvadi, PAnuvadi*, 'sa', 'pa', 'ma'}.

Nitya Sama swaras= {*Vadi, Samvadi, PAnuvadi*, 'sa', 'pa', 'ma'}.

Law of Co-existence of *Swaras*: Based on the *Shadja-Panchama Bhava* and

Shadja-Madhyama Bhava, the presence of certain pairs of *swaras*, becomes mandatory in a *Raga* generation process and Raga rendering. If one member of such a pair of *swaras* is present in the *Raga* then it necessitates the presence of the other member of the pair. The list of such pairs is given below. These are termed COX Pairs.

COX Pairs = {< ‘sa’-‘pa’>, <‘sa’-‘ma’>, <‘re’-‘pa’>, <‘kre’-‘mat’>, <‘ga’-‘ni’>, <‘kga’-‘kni’>, <‘ma’-‘kni’>, <‘mat’-‘ni’>}. This list is not exhaustive and can be expanded by following the above-mentioned laws of consonance.

Law of Emotive *Swaras*: These are the semitone *swaras* or the chromatic *swaras* that bring emotional flavour to the *Raga*. These are- ‘kre’, ‘kga’, ‘mat’, ‘kdha’, and ‘kni’. Along with them, their further microtonal/quarter-tone variations play a very important role in creating and augmenting the mood of the *Raga*. These *swaras/shrutis* are mostly from Bharat Muni’s *Saptaka*- ‘bre’, ‘bga’, ‘bdha’ and ‘bni’. *Swaras* like ‘cmat’, ‘cma’ and ‘csa’ also contribute in a significant way.

LMLs comprise the above laws however apart from that certain factors/ laws influence the *Raga* generation and rendering processes. These factors include *swara* phrases of various types which are discussed briefly as follows.

LGP: A *Raga* is rendered with the help of various types of *swara* phrases. When two or more *swaras* are placed together a *swara* phrase is generated. There can be a phrase of a single *swara* as well. There are many types of phrases. Some phrases have *swaras* in the defined sequences of either *Aroha* or *Avroha*. These are called *Krama* phrases or sequential phrases in GTIM. Some small phrases of two or three *swaras* can have *swaras* with minor or major jumps breaking the sequential order. Such phrases are called *Meend* phrases. Then there are phrases of mixed sequences of *Arohi swaras* and *Avrohi swaras*. These are called *Sanchari* phrases. There is another set of phrases which is called a set of *Alamkara* phrases. These phrases have beautiful patterns of *swara* arrangements. Along with them, there are many varieties of such beauty phrases such as consecutive *swara*-form phrases, and *Layakari Aalaps* and *Taanas*. These are described as follows.

Beauty or Aesthetic Phrases: If ornamentation phrases called ‘*Alamkara*’ phrases are generated around emotive *swaras*, *PAnuvadi swaras* and both the *Anu-Anuvadi swaras*, then that brings in the aesthetic flavour to the rendering of a *Raga*. These are small or medium size phrases with three to eight *swaras* generated by repetitive patterns of *swaras* or by oscillating initial, middle or last *swara* in a phrase. Aesthetic effects are created by repeating patterns, oscillations or vibrations of key *swaras*. Traditionally some of these aesthetic phrases are called ‘*Gamaka*’ phrases.

Consecutive Forms of *Swaras*: When two or three forms of the same *swara* such as ‘ma’ and ‘mat’; ‘kni’ and ‘ni’ or even ‘bga’, kga’ and ‘ga’ come consecutively in a *Raga* rendering that creates an effect that brings in emotional content to a *Raga*. For instance, in *Raga Megha*, the rendering of swaras ‘kni’ and ‘ni’ in a consecutive fashion brings in the *Raga* ‘*Megha*-ness’ in the rendering. Such consecutive *swara* forms or combinations with other *swara* phrases are responsible for developing the concept called ‘*Raganga*’. Of course, there are other factors contributing to the *Raganga* concept as well.

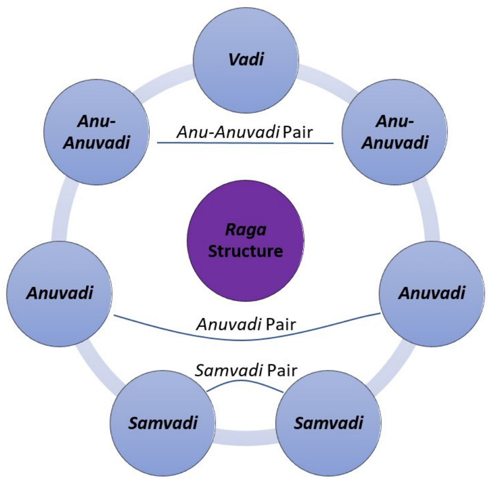
Layakari Alaaps* and *Taans: These are the extended versions of the above-mentioned aesthetic phrases. They involve, *Oudava* (five *swaras*), *Shadava* (six *swaras*), and *Sampurna* (seven *swaras*) as basic phrases and build patterns of ornamentations of various types of desired lengths. Most of the time these patterns are coordinated along with the patterns of beats or *Tala* patterns. Though it is not a mandatory feature, most of the time they are generated by following the rules of *Graha* and *Nyasa*. It means that their starting *swaras* are the *Graha swaras* and the ending *swaras* are the *Nyasa swaras*.

The description of the formal structure of *Raga* ends here. The next few chapters show how this abstract formal structure is manifested in the actual generative process. In the next chapters initially, the concept of *Gana* is elaborately discussed and then it is shown how the seed *Ragas* evolve through the process of generating variations on the original *Ganas*. The seed *Ragas* are hypothetical *Ragas* that go through a rigorous process of rejection and selection by applying musical criteria. The valid seed *Ragas* gets selected and qualifies as real *Ragas*. The next chapter

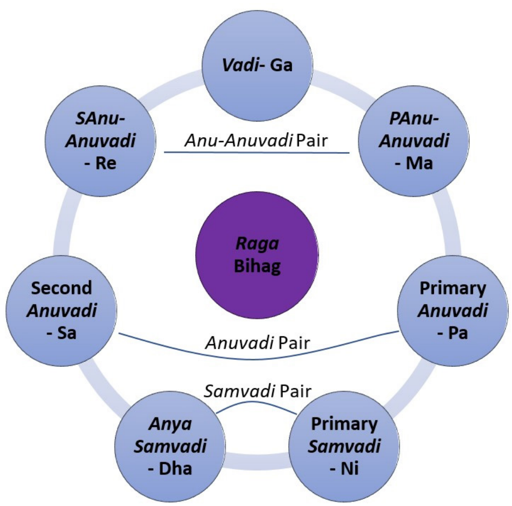
elaborates on various aspects of this process. This chapter was dedicated to the formal characterization of the concept of *Raga*.

The following charts will depict the broad structure of a *Raga*.

Generic *Raga* Structure



The Structure of the *Raga Bihag*



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CHAPTER 11

The *Nava Gana Raga* System

Moorchchhanas- A precursor to *Gana* System

During Bharata Muni's times, there was no *Raga* system. There existed a *Jati* system which is elaborately discussed in *Natyashastra*. It is believed that the *Raga* system evolved from the *Jati* system [Kulkarni, R. S., 1985, pp. 21]. There is a truism in this statement in the sense from a historical point of view we can see certain patterns of evolution of *Ragas* that match with the *Jati* system. But there is another aspect of the *Raga* system that is less known. Along with the *Jati* system, there was also a *Moorchchhana* system and a *Taana* system. *Natyashastra* has a highly sophisticated and codified description of *Moorchchhana* [Brihaspati, 1986, pp. 54-70]. There is strong evidence that suggests that the *Raga* system has evolved out of the *Moorchchhana* system. So before going into the description of the *Gana* system and the *Raga* system, we need to have a brief understanding of *Moorchchhanas*.

There was a *Grama* structure of *Shadja Grama*, *Madhyama Grama* and *Gandhara Grama* (the last one became obsolete during Bharata Muni's times) prevalent during Bharata Muni's times. *Grama* is a group of *swaras* on a scale. Within the *Gramas,* there were *Jatis* in each *Grama*. These systems are not very much relevant for today's music still we can say that all the contemporary music belongs broadly to *Shadja Grama*. However, the concepts of *Moorchchhana* and *Taana* are theoretically relevant to contemporary music. It can be shown that the *Ragas* have evolved out of *Moorchchhanas* and the classification system of categorizing *Ragas* as *Oudava, Shadava* and/ or *Sampurna Ragas* has evolved from the *Taana* system. It will be clarified at appropriate places as the discussion about the *Gana* system and *Ragas* proceeds.

It is necessary to first understand what is a *Moorchchhana*. A *Saptaka* is a sequence of seven *swaras* starting with the tonic *swara* Sa. This original *Saptaka* is considered the base *Moorchchhana* with the first *swara* as the tonic Sa. If any *swara* from the *Saptaka* is chosen as a tonic *swara*, i.e., the starting *swara* of a *Saptaka*, then the next seven *swaras* in a sequence comprise a new

Moorchchhana. So, if a *swara* Ga is chosen as a new tonic then the sequence of *swaras* like Ga, Ma, Pa, Dha, Ni, higher Sa, higher Re, and higher Ga, will be the new *Saptaka*/ an octave. This new *Saptaka* is considered a new *Moorchchhana*. [According to some scholars the sequence is reverse i.e., Ga, Re, Sa, lower, Ni, lower Dha, lower Pa, lower Ma]. By this process, there can be seven re-established *Saptakas* or *Moorchchhanas* for seven *swaras*. During Bharata's times, the *Saptaka* was different. Bharata's standard *Saptaka* was made of Sa, BRe (Bharata Muni's *Rishabha*), BGa (Bharata Muni's *Gandhara*), Ma, Pa, BDha (Bharata Muni's *Dhaivata*) and BNi (Bharata Muni's *Nishada*) *swaras*. For each *Moorchchhana* they had given a special name to identify the *Moorchchhana*. Names of seven *Moorchchhanas* of the *Shadja Grama* were *Uttaramandra, Rajani, Uttarayata, Shuddhashadja, Matsarikruta, Ashwakranta, Ashwakranta,* and *Abhirudgata*. Details of the first *Moorchchhans* called Uttaramandra during Bharata Muni's times are provided as follows as an example.

Description of *Uttaramandra Moorchchhana* is as follows-
First *Swara* of the *Moorchchhana* is: Sa
Shuddha form of the *Moorchchhana* is: sa, bre, bga, ma, pa, bdha, bni

During Bharata's times, there was a norm to modify the original *Moorchchhana* known as *Uttaramandra.* This is the first *Moorchchhana* of *Shadja Grama*. By replacing specific *swaras* with their *swara*-forms you get variations on the *Moorchchhana*. For instance, the original *Moorchchhana* can be modified by changing the BGa *swara* and/ or BNi *swara* by their respective alternative *swaras* as KGa or Ga and/ or KNi or Ni. For example, from *Uttaramandra Moorchchhana* we get four variations as follows based on this norm.

If we change bga to ga then a new *Moorchchhana* is generated which is called *Santara Moorchchhana* because, during Bharata Muni's times, *swara* Ga was known as *Aantar Gandhara*.

Santara form of the *Moorchchhana* is: sa, bre, **ga**, ma, pa, bdha, bni.

If we change bni to ni then a new *Moorchchhana* is generated which is called *Sakakali Moorchchhana* because, during Bharata Muni's time, *swara* ni was known as *Sakakali Nishad*.

Sakakali form of the *Moorchchhana* is: sa, bre, bga, ma, pa, bdha, **ni**.

If we change bga to ga and bni to ni then a new *Moorchchhana* is generated which is called *Ubhayayukta Moorchchhana* because both the bga and bni *swaras* are changed to ga and ni.

Ubhayayukta form of the *Moorchchhana* is: sa, bre, **ga**, ma, pa, bdha, **ni**.

Thus, the description of *Uttaramandra Moorchchhana* with its three variations is complete as above.

The above-mentioned *Moorchchhana* variations are given for the first *Moorchchhana* called *Uttaramandra* of *Shadja Grama*, which starts with *Shadja swara* in Bharata Muni's system. For brevity, here the detailed description of other *Moorchchhanas* is not given. A similar description is possible for *Madhyama Grama Moorchchhanas* and *Gandhara Grama Moorchchhanas*. This is the way Bharata Muni has developed the scheme of generating *Moorchchhanas* from the original *Saptaka*.

These original *Moorchchhanas* have seven *swaras* and therefore they are also called *Sampurna Moorchchhana* or *Sampurna Taana*. By eliminating one or two *swaras* from the *Sampurna Moorchchhana* we can generate *Shadava* and *Oudava Taanas*. The description of *Tanas* is provided in another chapter at an appropriate place. From a computational point of view, this approach appears to be highly logical and mathematically significant.

The above description provides us with the sophisticated approach adopted in Bharata Muni's *Natyashastra*. Pandit Venkatamakhin has followed the same line of thinking while developing his scheme of 72 *Melakarta Ragas*. Similarly, Pandit Bhatkhande developed a system of ten *Thaata*, which is a kind of subset of the 72 *Mela* system. A detailed description of both systems is not provided here because both systems have more or less followed the same approach. Extending the same line of thinking further and making it suitable for contemporary music a new system of *Raga* classification and analysis is developed and named as *Nava Gana* system of *Raga* classification. It is tested and validated by using computational technology.

Till the medieval period, there was a convention of mentioning the name of the generative *Moorchchhana* in the *Raga* description. For instance, Damodara Pandit in his treatise called *Sangit Darpan* [Kulkarni, R. S., 1985, p.85] follows the norm of mentioning the name of *Moorchchhana* in the *Raga* description along with *Graha, Amsha and Nyasa swaras*. But somehow this norm is not followed by other authors who wrote treatises on music. However, still it is possible to connect contemporary music with Bharata Muni's theoretical tradition by referring to the medieval norm of associating *Ragas* with the *Moorchchhana* system.

The *Nava Gana* System

The previous chapter deals with the characterization of the concept of *Raga*. We already developed a formal model of *Raga*. *Raga* as a conceptual structure made up of six factors made up of a tonic *swara*, a set of ascending *swaras* called *Aroha*, a set of descending *swaras* called *Avroha*, *Vadi swara, Samvadi swara, a set of Varjya swaras* and a set of generative laws capture all the salient features of a *Raga*. Now it is necessary to describe how these *Ragas* are manifested. The *Nava Gana* system that is being described in this chapter helps in understanding how *Ragas* are generated and how they can be classified. The unique property of the *Nava Gana* system is that it unifies the generative process of *Ragas* with a classification scheme for *Ragas*.

Bharata Muni's *Saptaka* is not in practice today. We can formulate modern-day *Moorchchhanas* using the contemporary *Saptaka* i.e., SS7= {sa, re, ga, ma, pa, dha, ni, hsa}. From this *Saptaka* we can generate modern-day *Moorchchhanas/ Ganas* in a step-by-step manner.

The initial tentative list of modern-day *Moorchchhanas* will be as follows.

Moorchchhana for Sa = {sa, re, ga, ma, pa, dha, ni}

Moorchchhana for Ni = {lni, sa, re, ga, ma, pa, dha}

Moorchchhana for Dha = {ldha, lni, sa, re, ga, ma, pa}

Moorchchhana for Pa = {lpa, ldha, lni, sa, re, ga, ma}

Moorchchhana for Ma = {lma, lpa, ldha, lni, sa, re, ga}

Moorchchhana for Ga = {lga, lma, lpa, ldha, lni, sa, re}

Moorchchhana for Re = {lre, lga, lma, lpa, ldha, lni, sa}

The above set of *Moorchchhanas* based on modern-day *Saptaka* is interesting in many ways. It resembles the *Melas* of Carnatic music or the *Thaata* system of North Indian music in some sense. But there is another way to interpret these *Moorchchhanas*. These *Moorchchhanas* can be treated as classes in themselves. The GTIM system redefines these classes as *Ganas*. These *Moorchchhanas/ Ganas* can be renamed as per their respective tonic *swaras*. So, for instance, *Moorchchhana* for Sa or *Shadja swara* can be renamed *Shadja Gana* and so on. After renaming, these *Moorchchhanas* as *Ganas* will look as follows.

Shadja Gana = {sa, re, ga, ma, pa, dha, ni}

Nishad Gana = {lni, sa, re, ga, ma, pa, dha}

Dhaivata Gana = {ldha, lni, sa, re, ga, ma, pa}

Panchama Gana = {lpa, ldha, lni, sa, re, ga, ma}

Madhyam Gana = {lma, lpa, ldha, lni, sa, re, ga}

Gandhar Gana = {lga, lma, lpa, ldha, lni, sa, re}

Rishabha Gana = {lre, lga, lma, lpa, ldha, lni, sa}

In the GTIM system, the *Nishad Gana* is not considered a valid *Gana* because the *Nishad swara* has inherent harmonic weakness and so cannot become a tonic of the *Moorchchhana*. This aspect of *Nishad swara* is already discussed in previous chapters. *Rishabha Gana, Gandhar Gana, and Dhaivata Gana* have one additional variation because these *swaras* have flat *swara* forms such as *Komal Rishabh, Komal Gandhar* and *Komal Dhaivata* respectively. The GTIM system, therefore, will have three additional *Ganas* dedicated to these *swaras*. They are represented as follows.

Komal Dhaivata Gana = {lkdha, lni, sa, kre, kga, ma, pa} – (kre and kga are mandatory part of the *Gana* because they are the *Samvadi swaras* of *Komal Dhaivata*).

Komal Gandhar Gana = {lkga, lma, lpa, lkdha, lkni, sa, re} – (kdha and kni are a mandatory part of the *Gana* because they are the *Samvadi swaras* of *Komal Gandhara*).

Komal Rishabha Gana = {lkre, lga, lmat, lpa, lkdha, lni, sa} – (mat and kdha are a mandatory part of the *Gana* because they are the *Samvadi swaras* of *Komal Rishabha*).

Now is the right time to start establishing norms for the *Gana* system. These norms are explained in the following few passages. The *Gana* system based on reinterpreted *Moorchchhanas* has distinct peculiarities as compared to the *Mela* system or *Thaata* system.

In the GTIM the tonic of a *Moorchchhana/ Gana* is considered as a *Gana swara*. The *Gana swaras* are also the *Vadi swaras* for the *Gana*. It means that all the *Ragas* that can be classified under a particular *Gana* will have the same *Vadi swara*. Therefore, appropriate changes need to be made for their respective *Samvadi* (and *Anya Samvadi*) *swaras* as done in the above representation of *Moorchchhanas/ Ganas* if necessary. For instance, when the *Gana swara* is *Komal Gandhar* inclusion of KDha and KNi *swara* is necessary for the *Gana* because they are the valid *Samvadi swaras* of Komal *Gandhara*.

So as a result, the final list of the *Ganas* will comprise *Shadja Gana, Komal Rishabha Gana, Rishabha Gana, Komal Gandhar Gana, Gandhar Gana, Madhyama Gana, Panchama Gana, Komal Dhaivata Gana,* and *Dhaivata Gana*. It can be seen that there is no *Nishada Gana* in the following list of nine *Ganas*. The list is as follows.

Shadja Gana = {sa, re, ga, ma, pa, dha, ni}

Komal Rishabha Gana = {lkre, lga, lmat, lpa, lkdha, lni, sa}

Rishabha Gana = {lre, lga, lma, lpa, ldha, lni, sa}

Komal Gandhara Gana = {lkga, lma, lpa, lkdha, lkni, sa, re}

Gandhara Gana = {lga, lma, lpa, ldha, lni, sa, re}

Madhyama Gana = {lma, lpa, ldha, lni, sa, re, ga}

Panchama Gana = {lpa, ldha, lni, sa, re, ga, ma}

Komal Dhaivata Gana = {lkdha, lni, sa, kre, kga, ma, pa}

So, in all, there are nine *Ganas* in the GTIM as major generic classes of *Ragas* and therefore they are called *Nava* (nine) *Ganas*. A detailed description of these nine *Ganas* is provided in the later part of this chapter. There is a separate Appendix IV at the end of the book dedicated to the classification of all the existing *Ragas* into these nine *Ganas*.

For the new system, certain new conventions need to be established and we need to understand their importance from the musical point of view. These conventions are formal conventions and attempt to bring in more clarity about the nature of *Ganas* and their formal structures. Such conventions are the insights that emerged out of the computational analysis of all the existing *Ragas*. For analysis, more than 400 *Ragas* from the North Indian system of music are closely studied. The 72 *Mela* system comes in very handy for the study of Carnatic music. Apart from that *Ragas* which are popular are also closely scrutinized for analysis. These insights are already discussed as Laws of Musical Logic in the earlier chapter. They are important in the *Raga* generation and classification process.

The *Nava Gana* system that is presented here is distinctly different from Bharata Muni's system and quite different from the traditional Carnatic music as well as contemporary *Thaata* systems. The new system is derived from the equal temperament 22 *shruti* paradigm of Bharata Muni in its spirit and further, it has taken the *Moorchchhana* system as the basis for *Raga* generation and classification. It may be said that the new system is inspired by Bharata Muni's system but repurposed for contemporary Indian music to address contemporary issues and problems. The following theoretical discussion carries forward the essence and spirit of Bharata Muni's system in a more rigorous way.

Generic *Swaras* for *Ganas*

Swara Sa is the base *swara* or a tonic of the *Saptaka*. Here SS12 has been taken as the base *Saptaka* for the description of *Ganas*.

SS12 = {sa, kre, re, kga, ga, ma, mat, pa, kdha, dha, kni, ni}

From this basic *Saptaka*, *Ganas* can be generated by assuming each member of SS12 as a tonic. *Gana* is a re-arranged *Saptaka* and the tonic *swara* of a *Gana* is considered as a *Vadi swara* for that particular *Gana*. All the melodic structures (*Ragas*) emerging out of a *Gana* will have the same tonic *swara* as a *Vadi swara*. It was found after analysis and research that the *swaras* Mat, KNi, and Ni are not entitled to become the *Vadi swaras* since they are harmonically weak. They are at the end of the order of the harmonic strength of *swaras*. The remaining nine *swaras* of SS12 are entitled to become *Vadi swaras* and the *Ganas* are named after them such as if Ga is a *Vadi*, then it is called *Gandhar Gana* and so on.

Samvadi swara is chosen by applying LML SP or LML SM to the *Vadi swara*.

So, for each *Gana,* there will be two possible *Samvadis*. Out of these two candidates *Samvadi swaras*, the stronger *swara* is chosen as the main *Samvadi* and the other *swara* is called *Anya Samvadi*. The *Anya Samvadi* is also equally important in *Raga* rendering.

Similarly, for each *Gana,* there will be a set of four *swaras* as candidate *Anuvadis*. These four swaras are selected by applying the LML SG or LML SKG or their inverses to the *Vadi swara*. Out of these four *swaras* two *swaras* are chosen that are strongest and also that are not *swara*-forms of each other. The strongest *Anuvadi* is called primary *Anuvadi* and the other one is called secondary *Anuvadi* swaras.

Similarly, for each *Gana,* there will be a set of four *swaras* as candidate *Anu-Anuvadis*. These four swaras are selected by applying the LML SR or LML SKR or their inverses to the *Vadi swara*. Out of these four *swaras* two *swaras* are chosen that are strongest and also that are not *swara*-forms of each other. The strongest one is called primary *Anu-Anuvadi* and the other one is called secondary *Anu-Anuvadi swaras*.

The above description can be articulated formally. As we developed a formal model of *Raga* in the previous chapter, in the same way, a formal model of *Gana* can be developed. A *Gana* can be considered as a 4-tuple made up of a *Vadi* list, *Samvadi* list, *Anuvadi* list and *Anu-Anuvadi* list. For computational convenience, this can be represented as follows.

Gana = [AAVL, AVL, SVL, VL].

In this 4-tuple, AAVL stands for *Anu-Anuvadi* list which has four members out of which two *swaras* will be selected in a *Raga*. AVL stands for *Anuvadi* list which has again four members and two *swaras* will be chosen for a *Raga*. SVL stands for *Samvadi* list which has two members and one of which is the main *Samvadi* and the other is called *Anya Samvadi*. VL stands for *Vadi* list which has only one member. For computational ease, the order of these members starts from AAVL to VL.

Gana is a generic class where the tonic is considered as a generic *Vadi swara* for the *Gana*. All the *Ragas* originating from the *Gana* will have the same *Vadi swara*. Similarly, there will be a main *Samvadi swara* and an *Anya Samvadi swara*, a pair of possible *Anuvadi swaras* and a pair of possible *Anu-Anuvadi swaras*. All the *swaras* are the generic *swaras* for the *Gana* and will be inherited by all the possible *Ragas* originating from the *Gana*. This description of all the *Ganas* is presented formally in the following paragraphs. In this regard, certain norms of representation for the formal treatment are as follows. The laws of musical inference are considered functions that operate on the tonic *swara* Sa. *Swara* Sa is represented as sa while (laws of musical inference) are represented by small case letters. For instance, LML SP is represented by sp and LML SM as sm. There exists one more LML called SMT that stands for *Shadja-Teevra Madhyama Bhava*. It is used very rarely and it may be represented as smt. The other laws are represented as- LML SG as sg, LML SKG as skg, LML SR as sr, LML SKR as skr, LML SD as sd, LML SKD as skd, LML SN as sn and LML SKN as skn.

The domain of description SS12 = {sa, kre, re, kga, ga, ma, may, pa, kdha, dha, kni, ni, has}. A set of *swaras* sa, pa, and ma is known as a set of *Nitya swaras* so Nitya = {sa, ma, pa} and pairs of swaras are denoted as <x, y>. The description of *Vadi, Samvadi, Anuvadi* and *Anu-Anuvadi swaras* of all the *Ganas* are given as follows

Shadja Gana Generic *Swaras*

Gana swara* and *Vadi: sa

***Samvadis*:**

sp (sa) = pa and

sm (sa) = ma

∴ *Samvadi* pairs = <pa, ma>.

Even <mat> needs to be mentioned here that is derived as smt (sa) = mat.

pa ∈ {sa, ma, pa} and ma ∈ {sa, ma, pa}

pa > ma

∴ pa is primary *Samvadi* and ma is secondary *Samvadi*

***Anuvadis*:**

sg (sa) = ga and

skg (sa) = kga

sd (sa) = dha and

skd (sa) = kdha

∴ Candidate *Anuvadis* = {ga, kga, dha, kdha} primary and secondary *Anuvadis* will be chosen by appropriately following the laws of musical logic.

***Anu-Anuvadis*:**

sr (sa) = re and

skr (sa) = kre

sn (sa) = ni and

skn (sa) = kni

∴ Candidate *Anu-Anuvadis* = {re, kre, ni, kni} primary and secondary *Anu-Anuvadis* will be chosen by appropriately following the laws of musical logic.

Similarly for other *Ganas Samvadi* pairs will be as follows.

Panchama Gana Generic *Swaras*

Gana swara* and *Vadi: pa

***Samvadis*:**

sp (pa) = re and

sm (pa) = sa

∴ *Samvadi* pairs = <re, sa>

Even <kre> needs to be mentioned here that is derived as smt (pa) = kre.

re ∉ {sa, ma, pa} and sa ∈ {sa, ma, pa},

sa > re,

∴ sa is primary *Samvadi* and re is secondary *Samvadi* or *Anya swara*

***Anuvadis*:**

sg (pa) = ni and

skg (pa) = kni

sd (pa) = ga and

skd (pa) = kga

∴ Candidate *Anuvadis* = {ni, kni, ga, kga} primary and secondary *Anuvadis* will be chosen by appropriately following the laws of musical logic.

***Anu-Anuvadis*:**

sr (pa) = dha and

skr (pa) = kdha

sn (pa) = mat and

skn (pa) = ma

∴ Candidate *Anu-Anuvadis* = {dha, kdha, mat, ma} primary and secondary *Anu-Anuvadis* will be chosen by appropriately following the laws of musical logic.

Madhyama Gana Generic *Swaras*

Gana swara* and *Vadi: ma

***Samvadis*:**

sp (ma) = sa and

sm (ma) = kni

∴ *Samvadi* pairs = <sa, kni>

sa ∈ {sa, ma, pa} and kni ∉ {sa, ma, pa}

sa > kni

∴ sa is primary *Samvadi* and kni is secondary *Samvadi* or *Anya swara*

Even <ni> needs to be mentioned here that is derived as smt (ma) = ni.

***Anuvadis*:**

sg (ma) = dha and

skg (ma) = kdha

sd (ma) = re and

skd (ma) = kre

∴ Candidate *Anuvadis* = {dha, kdha, re, kre} primary and secondary *Anuvadis* will be chosen by appropriately following the laws of musical logic.

Anu-Anuvadis:

sr (ma) = kdha and (The *swara* mat is not valid being the *swara*-form of ma).

skr (ma) = pa

sn (ma) = ga and

skn (ma) = kga

∴ Candidate *Anu-Anuvadis* = {kdha, pa, ga, kga} primary and secondary *Anu-Anuvadis* will be chosen by appropriately following the laws of musical logic.

Gandhara Gana Generic *Swaras*

Gana swara* and *Vadi: ga

Samvadis:

sp (ga) = ni and

sm (ga) = dha

∴ *Samvadi* pairs = <ni, dha>

ni ∉ {sa, ma, pa} and dha ∉ {sa, ma, pa}

LML COX <ga, ni>

Though dha > ni,

∴ ni is primary *Samvadi* and dha is secondary *Samvadi or Anya swara*

Even <kni> needs to be mentioned here that is derived as smt (ga) = kni.

Anuvadis:

sg (ga) = pa and

skg (ga) = pa

sd (ga) = sa and

skd (ga) = sa

∴ Candidate ***Anuvadis*** = {pa, sa} primary and secondary *Anuvadis* will be chosen by appropriately following the laws of musical logic.

***Anu-Anuvadis*:**

sr (ga) = mat and

skr (ga) = ma

sn (ga) = re and

skn (ga) = kre

∴ Candidate *Anu-Anuvadis* = {mat, ma, re, kre} primary and secondary *Anu-Anuvadis* will be chosen by appropriately following the laws of musical logic.

Rishabha Gana Generic *Swaras*

Gana swara* and *Vadi: re

***Samvadis*:**

sp (re) = dha and

sm (re) = pa

∴ *Samvadi* pairs = <dha, pa>

pa $\in$ {sa, ma, pa} and dha $\notin$ {sa, ma, pa}

pa > dha

∴ pa is primary *Samvadi* and dha is secondary *Samvadi* or *Anya swara*

Even <kdha> needs to be mentioned here that is derived as smt (re) = kdha.

***Anuvadis*:**

sg (re) = mat and

skg (re) = ma

sd (re) = kni and

skd (re) = ni

∴ Candidate *Anuvadis* = {mat, ma, kni, ni} primary and secondary *Anuvadis* will be chosen by appropriately following the laws of musical logic.

***Anu-Anuvadis*:**

sr (re) = ga and

skr (re) = kga

sn (re) = sa and

skn (re) = ni

∴ Candidate *Anu-Anuvadis* = {ga, kga, sa, ni} primary and secondary *Anu-Anuvadis* will be chosen by appropriately following the laws of musical logic.

Komal Gandhara Gana Generic *Swaras*

Gana swara* and *Vadi: kga

***Samvadis*:**

sp (kga) = kni and

sm (kga) = kdha

∴ *Samvadi* pairs = <kni, kdha>

kni ∉ {sa, ma, pa} and kdha ∉ {sa, ma, pa}

LML COX <kga, kni>

Though kdha > kni,

∴ kni is primary *Samvadi* and kdha is secondary *Samvadi* or *Anya swara*

Even <dha> needs to be mentioned here that is derived as smt (kga) = dha.

***Anuvadis*:**

sg (kga) = pa and

skg (kga) = pa

sd (kga) = sa and

skd (kga) = sa

∴ Candidate *Anuvadis* = {pa, sa} primary and secondary *Anuvadis* will be chosen by appropriately following the laws of musical logic.

***Anu-Anuvadis*:**

sr (kga) = ma and

skr (kga) = ga (This not applicable because kga and ga are the swara-forms of each other)

sn (kga) = re and

skn (kga) = kre

∴ Candidate *Anu-Anuvadis* = {ma, re, kre} primary and secondary *Anu-Anuvadis* will be chosen following above-mentioned rules

Komal Rishabha Gana Generic *Swaras*

Gana swara* and *Vadi: kre

***Samvadis*:**

sp (kre) = kdha and

sm (kre) = mat

∴ *Samvadi* pairs = <kdha, mat>

kdha ∉ {sa, ma, pa} and mat ∉ {sa, ma, pa}

kdha > mat,

∴ kdha is primary *Samvadi* and mat is secondary *Samvadi* or *Anya swara*

Even <pa> needs to be mentioned here that is derived as smt (kre) = pa.

***Anuvadis*:**

sg (re) = mat and

skg (re) = ma

sd (re) = kni and

skd (re) = ni

∴ Candidate *Anuvadis* = {mat, ma, kni, ni} primary and secondary *Anuvadis* will be chosen by appropriately following the laws of musical logic.

***Anu-Anuvadis*:**

sr (kre) = kga and

skr (kre) = re (This is not applicable as re and kre are the *swara*-forms of each other).

sn (kre) = sa and

skn (kre) = ni

∴ Candidate *Anu-Anuvadis* = {kga, sa, ni} primary and secondary *Anu-Anuvadis* will be chosen by appropriately following the laws of musical logic.

Dhaivata Gana Generic *Swaras*

Gana swara* and *Vadi: dha

***Samvadis*:**

sp (dha) = ga and

sm (dha) = re

∴ *Samvadi* pairs = <ga, re>

ga ∉ {sa, ma, pa} and re ∉ {sa, ma, pa}

ga > re,

∴ ga is primary *Samvadi* and re is secondary *Samvadi* or *Anya swara*

Even <kga> needs to be mentioned here that is derived as smt (dha) = kga.

***Anuvadis*:**

sg (dha) = kre and

skg (dha) = sa

sd (dha) = mat and

skd (dha) = ma

∴ Candidate *Anuvadis* = {kre, sa, mat, ma} primary and secondary *Anuvadis* will be chosen by appropriately following the laws of musical logic.

***Anu-Anuvadis*:**

sr (dha) = ni and

skr (dha) = kni

sn (dha) = kdha (This is not applicable as dha and kdha are the *swara*-forms of each other).

skn (dha) = pa

∴ Candidate *Anu-Anuvadis* = {ni, kni, pa} primary and secondary *Anu-Anuvadis* will be chosen by appropriately following the laws of musical logic.

Komal Dhaivata Gana Generic *Swaras*

Gana swara* and *Vadi: kdha

***Samvadis*:**

sp (kdha) = kga and

sm (kdha) = kre

∴ *Samvadi* pairs = <kga, kre>

kga ∉ {sa, ma, pa} and kre ∉ {sa, ma, pa}

kga > kre,

∴ kga is primary *Samvadi* and kre is secondary *Samvadi* or *Anya swara*

Even <re> needs to be mentioned here that is derived as smt (kdha) = re.

***Anuvadis*:**

sg (kdha) = kre and

skg (kdha) = sa

sd (kdha) = mat and

skd (kdha) = ma

∴ Candidate *Anuvadis* = {kre, sa, mat, ma} primary and secondary *Anuvadis* will be chosen by appropriately following the laws of musical logic.

***Anu-Anuvadis*:**

sr (kdha) = kni and

skr (kdha) = dha %not applicable

sn (kdha) = pa and

skn (kdha) = mat

∴ Candidate *Anu-Anuvadis* = {kni, pa, mat} primary and secondary *Anu-Anuvadis* will be chosen by appropriately following the laws of musical logic.

Important Considerations for *Gana* System

Moorchchhanas system from *Natyashastra* of Bharata Muni is the basis of the *Raga* generation process and classification in GTIM. Contemporary Indian music is quite different from the ancient music. However, the basic tenets of the *Moorchchhana* system are still intact and valuable. A detailed description of how the *Moorchchhana* system and the new system are related is done in earlier sections. In the GTIM system, there are nine *Ganas* which are inspired by the *Moorchchhana* system. Normally if we follow the sequence of *swaras* in a *Saptaka* the first *Gana* should be *Shadja Gana* and the last *Gana* would be *Komal Dhaivata Gana*. However, it becomes necessary to organize *Ganas* in a slightly different order. In GTIM the *Ganas* are organized as per the law of harmonic strength of *swaras*. Accordingly, the *Ganas* are organized as follows – *Panchama Gana, Madhyama Gana, Gandhar Gana, Rishabha Gana, Komal Gandhar Gana, Komal Rishabha Gana, Dhaivata Gana, Komal Dhaivata Gana* and finally *Shadja Gana.* The *Shadja Gana* is kept at the end in the above order because it is considered a *Prakirna Gana*. This needs some explanation as follows.

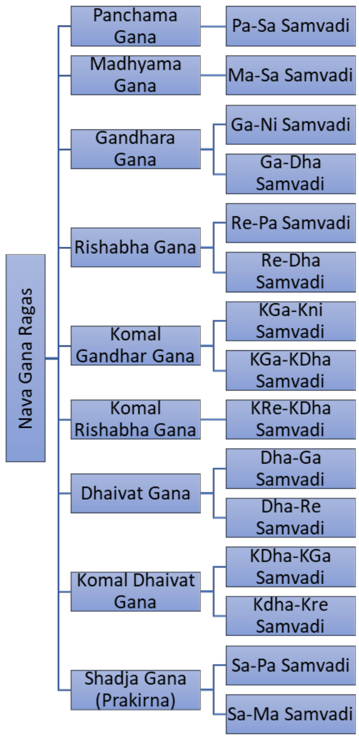
With the above-mentioned considerations, the new system has nine *Ganas* as mentioned above. It is possible to classify all the existing and all the possible *Ragas* by following the logic of the system. Apart from the standard regular *Ragas*, there exist many *Ragas* that have some peculiar characteristics and deviant behaviour. All such *Ragas* are classified separately. This *Gana* is called '*Prakirna*' *Gana*. The main feature of this *Gana* is that all such *Ragas* have their *Vadi swara* as *Shadja* by default. There is a reason behind such an arrangement. These *Ragas* are highly complex in their structure. For instance, *Ragas* having two *Varjya swaras* in the *Aroha* and two completely different *Varjya swaras* in the *Avroha* will be complicated for *Raga* to perform. Any standard *Gana swara* cannot do full justice as a *Vadi swara* for such a *Raga*. However, *Shadja* being a tonic of the scale is harmonically strong. So, it can become a *Vadi* of such a *Raga*. If *Shadja* becomes *Vadi* then naturally either Pa or Ma becomes the main *Samvadi* depending on their structural position and strength in the *Raga*. In the same way, *Anuvadis* and *Anu-Anuvadis* can be decided for such a *Raga*. In all such *Ragas*, therefore, Pa or Ma gets prominence and to a great extent, these *swaras* behave more than *Samvadis*. Although *Shadja* is a default *Vadi* for these *Ragas*, Pa or Ma also show their presence dominantly because naturally, *Shadja* is a neutral *swara* due to its omnipresence.

Apart from being structurally complex, these *Ragas* of the *Prakirna Gana* may have some deviant characteristics or some unique features. These peculiarities and unique qualities make these *Ragas* significant. There are three main types of such *Prakirna Ragas* as per the GTIM. There are *Ragas* with different *Varjya swaras* in *Aroha* and *Avroha.* For example, *Raga Gavati* has Re and Dha as *Varjya swaras* in *Aroha* while in *Avroha* it has *Komal Ni* as a *Varjya swara*. As a norm, if there are more than two *Varjya swaras* including *Aroha* and/ or *Avroha* then such *Ragas* are considered under this category. There is a *Raga Bahar* which has Ga and Dha as *Varjya swaras* in *Aroha* and *Avroha* respectively. But this Raga will not come under this category because the total number of *Varjya swaras* is not more than two. But in the case of *Raga Malarani*, it has *Ga, Dha Varjya swaras* in *Aroha* and *Mat,* and *Ni as Varjya swaras* in *Avroha*. So, this *Raga* will come under *Prakirna Gana*.

There are a few *Ragas* that use three *swara forms* of Ga as- Ga, KGa, AKGa and Ni- Ni, KNi, AKNi. These *Ragas* are called *Tri-Gandhar Ragas* in GTIM. The *Raga Lagan Gandhara* that has all three *Gandhar swara* forms will fit in this category. There are some *Ragas* that have multiple dual forms of *swaras* used. For instance, some Ragas have two *swara* forms of Ma- Ma and Mat, two *swara* forms of Ni- Ni and KNi, and two *swara* forms of Re- Re and KRe. *Raga Vasant Bahar* has dual forms of Re, Ga, Ma and Ni *swaras*. In such a case a *Raga* becomes very complex to render. Again, here the norm is if there are two *swaras* with their respective *swara*-forms then these *Ragas* will come under regular *Ragas*. But if three or more *swaras* have their respective *swara*-forms in the *Raga* then such *Ragas* will come under the *Prakirna* category. All such types of *Ragas* are classified as *Prakirna Ragas* and by default their *Vadi swara* is *Shadja*. Apart from these main types of *Prakirna Ragas*, some Ragas have only four *swara*. Such *Ragas* are known as '*Chatuh-Swari*' *Ragas* or *Chatura Ragas*. Though these *Ragas* do not fit into the definition of *Raga*, they are clubbed under this category just as an additional category. A brief explanation of *Prakirna Ragas* is complete here.

The objective of this chapter was to formulate the *Nava Gana* system for the classification of *Ragas*. More details of the *Nava Gana* system are presented in the following chapters. The *Nava Gana* system is also a generative system. Following chapters throw light on how this broader framework of the *Nava Gana* system helps in understanding the *Raga*-generation process in a step-by-step manner. Eventually, all the existing *Ragas* as well as all the possible *Ragas* are classified within the framework of the *Nava Gana* system. This chapter gives an overview of the *Nava Gana* system. For ease of understanding, the *Gana* hierarchy is captured in the following chart. The root of the chart is *Nava Gana Ragas*. It has nine stems for nine *Ganas* starting with a *Panchama Gana* and ending with the *Shadja Gana* which is also called *Prakirna Gana* because it is comprised of deviant *Ragas*. For each *Gana* sub-branches of possible *Samvadis* are also shown in the chart.

A Chart of *Nava Gana Ragas*



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CHAPTER 12

Ragas in Making: Seed *Ragas*

Introduction

The previous chapter discusses the salient features of *Ganas*. It was mentioned there that the *Ragas* can be generated from *Ganas* and at the same time they are classified in *Ganas*. So, the *Gana* system is a generative system as well as a classification system. This chapter will focus on the generation process in a step-by-step manner. *Ragas* are generated within *Ganas* in multiple stages. Initially, A set of *Ragas* is generated as potential *Ragas* and then certain criteria of musical logic are applied to make them real *Ragas*. This process is a multi-stage process that is articulated in this chapter and in the next few chapters.

As it is discussed in the previous chapter, each *Gana* has the original set of seven *swaras*. *Ganas* are inspired by traditional *Moorchchhanas*. Traditionally, each *Moorchchhana* had three additional variations as *Saantara Moorchchhana* that is having *Antar Gandhara swara*, *Sakakali Moorchchhana* has *Kakali Nishad* and the *Ubhaya Moorchchhana* that has *Antara Gandhara* as well as *Kakali Nishad swaras* as variations. In the GTIM system, there will be variations on each *Ganas*. In the GTIM system *swaras* such as re, ga, dha, and ni have a flat variation and the *swara* ma has a sharp variation called '*Teevra Madhyama*' or Mat. By making changes to the *swaras* of *Ganas* we generate variations. Except Sa and Pa, all the other *swaras* have flat, or sharp variations. The pure *swaras* of a *Gana* can be replaced by flat or sharp and flat *swaras* of a *Gana* can be replaced by pure *swaras* to generate variations. This process leads to several variations in each *Gana*.

These variations are considered as the potential *Ragas* in the GTIM system. As it stands, these variations are not the real *Ragas*. This is just the first step in the process of *Raga* generation. These variations are 'possible' *Ragas*. After applying certain criteria to these variations some of the variations may not qualify as *Ragas* and some of them will be rejected. Some other variations may need some more modifications to attain the status of a *Raga*. These variations including the original *Gana swaras* generate a pool of possible *Ragas* for a particular *Gana*. As it is explained, the members of this pool may attain the status of real *Ragas* with rule-based changes or modifications by applying certain criteria. The laws of musical logic (LML) act as the criteria and play a very important role in this process. Before getting the status of *Raga* all these variations are considered as 'Seed *Ragas*' or the '*Beeja Ragas*' in the GTIM. Each *Gana* generates a set of such seed *Ragas* and out of this set after applying the laws of musical logic in a systematic way the real *Ragas* are generated. This is the process of *Raga* generation from *Ganas* in brief. This process may be illustrated with a few examples.

Shadja Gana – Seed *Ragas*

As an example, by implementing the flat variations on the *swaras* of the *Shadja Gana* for instance, we get additional 15 variations. It means that we can replace the pure forms of *swaras* re, ga, dha, and ni with their respective flat variation and generate all possible permutations for *Shadja Gana*. So, including the original version itself, the *Shadja Gana* will have 16 variations in total. They are shown as follows. Apart from that if we make *swara* 'ma' of each of these variations as 'mat'- the sharp variation of 'ma' *swara*, then we get 16 more variations from them. So, in total, we will have 32 variations for *Shadja Gana* as shown below.

Shadja Gana = {sa, re, ga, ma, pa, dha, ni} -Original version leading to 1 variation.

(Only one *swara* is made flat out of re, ga, dha, and ni leading to 4 variations.)

Shadja Gana = {sa, kre, ga, ma, pa, dha, ni} -re is changed to kre

Shadja Gana = {sa, re, kga, ma, pa, dha, ni} -ga is changed to kga

Shadja Gana = {sa, re, ga, ma, pa, kdha, ni} -dha is changed to kdha

Shadja Gana = {sa, re, ga, ma, pa, dha, kni} -ni is changed to kni

(Two *swaras* are made flat out of re, ga, dha, and ni leading to 6 variations.)

Shadja Gana = {sa, kre, kga, ma, pa, dha, ni}-has kre and kga

Shadja Gana = {sa, re, kga, ma, pa, kdha, ni}-has kga and kdha

Shadja Gana = {sa, re, ga, ma, pa, kdha, kni}-has kdha and kni

Shadja Gana = {sa, kre, ga, ma, pa, kdha, ni}-has kre and kdha

Shadja Gana = {sa, re, kga, ma, pa, dha, kni}-has kga and kni

Shadja Gana = {sa, kre, ga, ma, pa, dha, kni}-has kre and kni

(Three *swaras* are made flat out of re, ga, dha, and ni leading to 4 variations.)

Shadja Gana = {sa, kre, ga, ma, pa, kdha, kni}- only ga is unchanged

Shadja Gana = {sa, re, kga, ma, pa, kdha, kni}- only re is unchanged

Shadja Gana = {sa, kre, kga, ma, pa, kdha, ni}- only ni is unchanged

Shadja Gana = {sa, kre, kga, ma, pa, dha, kni}- only dha is unchanged

(All four *swaras* from re, ga, dha, ni are made flat leading to 1 variation.)

Shadja Gana = {sa, kre, kga, ma, pa, kdha, kni}

In all 1+4+6+4+1 = 16 variations are possible for *Shadja Gana* in this manner.

If we make the *Madhyama* i.e., 'ma' sharp in all the above variations then we will get 16 more variations as follows.

Shadja Gana = {sa, re, ga, mat, pa, dha, ni} -Original

(Only one swara is made flat out of re, ga, dha, ni)

Shadja Gana = {sa, kre, ga, mat, pa, dha, ni} -re is changed to kre

Shadja Gana = {sa, re, kga, mat, pa, dha, ni} -ga is changed to kga

Shadja Gana = {sa, re, ga, mat, pa, kdha, ni} -dha is changed to kdha

Shadja Gana = {sa, re, ga, mat, pa, dha, kni} -ni is changed to kni

(Two swaras are made flat out of re, ga, dha, ni)

Shadja Gana = {sa, kre, kga, mat, pa, dha, ni}-has kre and kga

Shadja Gana = {sa, re, kga, mat, pa, kdha, ni}-has kga and kdha

Shadja Gana = {sa, re, ga, mat, pa, kdha, kni}-has kdha and kni

Shadja Gana = {sa, kre, ga, mat, pa, kdha, ni}-has kre and kdha

Shadja Gana = {sa, re, kga, mat, pa, dha, kni}-has kga and kni

Shadja Gana = {sa, kre, ga, mat, pa, dha, kni}-has kre and kni

(Three swaras are made flat out of re, ga, dha, ni)

Shadja Gana = {sa, kre, ga, mat, pa, kdha, kni}

Shadja Gana = {sa, re, kga, mat, pa, kdha, kni}

Shadja Gana = {sa, kre, kga, mat, pa, kdha, ni}

Shadja Gana = {sa, kre, kga, mat, pa, dha, kni}

(All four swaras from re, ga, dha, ni are made flat)

Shadja Gana = {sa, kre, kga, mat, pa, kdha, kni}

The above description provides us with a method to generate variations on the base *Moorchchhana* or the original set of *swaras* for contemporary *Saptaka*. It does not mean that for each *Gana* there will be 32 variations. *Madhyama Gana* will not have variations generated due to Mat *swara* because mat is a *swara* form of ma *swara*. Similarly, *Komal Gandhar Gana* will have even fewer variations because there will not be any variations related to *Shuddha Gandhara* there for the same reason. It will be more interesting to develop a formal way to represent variations on the original *Ganas*. The above method is taken forward by making it more sophisticated and useful for computational implementation.

The last section of this chapter is dedicated to the description of the seed *Ragas* in each *Gana* in a formal way. The traditional method for generating variations is operationally sound. But it requires a more robust formal justification therefore, it is necessary to develop a formal methodology to arrive at the description of seed *Ragas*. In the process, many technical concepts and relationships relevant to the *Raga* generation will be addressed in a structured way. Along with-it computational conventions are developed that are useful for writing programs. The next section is devoted to the development of such a formal method. The conventions developed in the next section are implemented for building two AI systems called *AIRaga* and thoroughly tested.

Formal Approach for Generating Seed *Ragas*

As already discussed, mapping of the ET-22 set onto SS12 is possible and consequently, the SS12 set can be further mapped onto set SS7. Now interestingly set SS7 can be represented using numerals as follows as a set SN7. By this, a group representation of a *Raga* can be extended for explaining the generative process.

SS7 = {sa, re, ga, ma, pa, dha, ni}. A permutation on itself is a bijection and SS7 can be represented as follows.

SS7 = {pa, dha, ni, sa, re, ga, ma}.

Now according to Axiom II, which is also an Axiom of octave equivalence, *swaras* pa, dha, and ni are equivalent to *swaras* lpa, ldha, and lni and can be represented as follows.

SS7 = {lpa, ldha, lni, sa, re, ga, ma}.

Thus, SS7 can be represented in numerical form as SN7 as follows.

SN7= {-3, -2, -1, 0, 1, 2, 3}

SS7 = {‘pa’, ‘dha’, ‘ni’, ‘sa’, ‘re’, ‘ga’, ‘ma’}- *Shadja Gana swaras.*

Here the numbers of the set SN7 represent the seven *swaras* of a *Saptaka* i.e., the set SS7. The *Saptaka* i.e., the set SS7 also stands for the SS12. In that case, twelve *swaras* of SS12 are mapped onto the seven *swaras* of SS7 and therefore this mapping is a surjection. Only the *swara* ‘sa’ and ‘pa’ from SS7 correspond with the *swaras* ‘sa’ and *swara* ‘pa’ of SS12 respectively. In the case of other *swaras*, each of the *swaras* of SS7 has two corresponding *swaras* in the set SS12. As shown below. This also means that the set SN7 eventually represents the set SS12.

SS12= {[‘pa’], [‘kdha’, ‘dha’], [‘kni’, ‘ni’], [‘sa’], [‘kre’, ‘re’], [‘kga’, ‘ga’], [‘ma’, ‘mat]}

SS7 = {‘pa’, ‘dha’, ‘ni’, ‘sa’, ‘re’, ‘ga’, ‘ma’}

Similarly, a surjection between the set ET22 and SS12 can be represented as follows.

ET22= {[‘cpa’, ‘pa’], [‘ckdha’, ‘kdha’, ‘bdha’, ‘dha’], [‘bni’, ‘kni’, ‘ni’], [‘csa’, ‘sa’], [‘ckre’, ‘kre’, ‘bre’, ‘re’], [‘bga’, ‘kga’, ‘ga’], [‘cma’, ‘ma’, ‘cmat’, ‘mat]}

SS12= {[‘pa’], [‘kdha’, ‘dha’], [‘kni’, ‘ni’], [‘sa’], [‘kre’, ‘re’], [‘kga’, ‘ga’], [‘ma’, ‘mat]}

For the time being, we will not discuss in detail about involving set ET22 here because set ET22 stands for Bharata Muni’s system and Bharata Muni’s system is not followed today as it is. So let us concentrate on the set SS12 and SS7 here. At an abstract level of analysis, if we perform numerical operations on the set SN7 then actually, we are performing the operations on the set SS12 as well. Since the correspondence between these three sets is already established, many of the *Raga*-related properties can be mapped and represented numerically for ease of understanding.

SN7 = {-3, -2, -1, 0, 1, 2, 3} stands for SS7 = {‘pa’, ‘dha’, ‘ni’, ‘sa’, ‘re’, ‘ga’, ‘ma’} and so following correspondence can be shown.

-3 = ‘pa’, -2 = ‘dha’, -1 = ‘ni’ and 0 = ‘sa’. Similarly, 1 = ‘re’, 2 = ‘ga’ and 3 = ‘ma’. Now when SS12 is mapped on to SN7 via SS7 following correspondence can be established.

-3 = ‘pa’ = [‘pa’], -2 = ‘dha’ = [‘kdha’, ‘dha’], -1 = ‘ni’ = [‘kni’, ‘ni’], and 0 = ‘sa’. = [‘sa’],

Similarly, 1 = ‘re’ = [‘kre’, ‘re’], 2 = ‘ga’ = [‘kga’, ‘ga’], and 3 = ‘ma’ = [‘ma’, ‘mat].

It means that -3 = [‘pa’], -2 = [‘kdha’, ‘dha’], -1 = [‘kni’, ‘ni’], and 0 = [‘sa’],

Similarly, 1 = [‘kre’, ‘re’], 2 = [‘kga’, ‘ga’], and 3 = [‘ma’, ‘mat].

This approach can be further extended to set ET22- Bharata Muni’s *shrutis* however, right now the focus is on the set SS7 and the set SS12.

This convention will be useful for taking the seed *Raga* generation discussion forward. This will help us in many respects in understanding the computational calculus of the *Raga* generation process at large.

For *Shadja Gana* the numerical representation, seven *swara* representations and twelve *swara* representations for *Raga* calculus will be as follows.

SS12= {[‘pa’], [‘kdha’, ‘dha’], [‘kni’, ‘ni’], [‘sa’], [‘kre’, ‘re’], [‘kga’, ‘ga’], [‘ma’, ‘mat]}

SS7 = {‘pa’, ‘dha’, ‘ni’, ‘sa’, ‘re’, ‘ga’, ‘ma’}

SN7 = {-3, -2, -1, 0, 1, 2, 3}

Let us consider 0 as a kind of identity element in SN7 that stands for *swara* ‘sa’. So, in the computational calculus of the *Raga* Generation process the *swara* ‘sa’ plays a role as a kind of identity element.

From SN7 following ordered pairs can be generated. Let us take the numbers whose absolute values are equal and generate the ordered pairs as follows.

|-1|=|1| have the same absolute value that stands for ‘ni’ and ‘re’ respectively. We can put them together as an ordered pair. So <‘ni’, ‘re’> but it also means that <‘ni’, [‘kre’, ‘re’]> because ‘kre’ stands for [‘kre’, and ‘re’] in the set SS12. In the same fashion |-2|=|2| and therefore <‘dha’, ‘ga> and <‘dha’, [‘kga’, ‘ga’]> are validated. Similarly, |-3|=|3| and so <‘pa’, ‘ma’> and <‘pa”, [‘ma’, ‘mat’]> are the valid ordered pairs. This pairing is also significant from the musical point of view.

If we take the ordered pair <‘pa’, ‘ma’> for our analysis then it is interesting to know that both the member *swaras* ‘pa’ and ‘ma’ are two *Samvadi swaras* of the *swara* ‘sa’ which is our identity element. So, if we treat the identity element ‘sa’ as a *Vadi swara* then ‘pa’ and ‘ma’ are the *Samvadi swaras* for this *Vadi*. As per the traditional theory from Bharata Muni’s *Natyashastra,* there exists a *Shadja-Panchama Bhava* between ‘sa’ and ‘pa’ *swara*. Similarly, there exists *Shadja-Madhyama Bhava* between ‘sa’ and ‘ma’ *swaras*. Technically, both the *Bhavas* are complementary to each other because the inverse of *Shadja-Panchama Bhava* is the *Shadja-Madhyama Bhava* and therefore it can be said that the *swaras* ‘pa’ and ‘ma’ are inverses of each other because computationally both *swaras* can be derived from the ‘sa’ *swara* by applying the same rule.

Similarly, in the case of the ordered pair <‘dha’, ‘ga>, it is interesting to note that both the *swaras* ‘ga’/’kga’ and ‘dha’/’kdha’ are the *Anuvadi swaras* of ‘sa’. So, if we consider ‘sa’ as a *Vadi swara* then ‘ga’ and ‘dha’ are the natural *Anuvadi swaras*. The relationship between *swara* ‘sa’ and swara ‘ga’ is known as *Shadja-Gandhara Bhava* as per traditional theories. The relationship between ‘sa’ and ‘dha’ is the inverse of *Shadja Gandhara Bhava*. So, from the point of view of the computational calculus of *Ragas,* these relationships are very important and these ordered pairs are also important.

By applying the same logic, we get the ordered pair <‘ni’, ‘re’>. In the traditional theories on *Ragas* somehow there is no discussion about the role of the *swaras* that are close to *Vadi swaras*. These *swaras* are considered as the '*Vivadi*' *swaras* as per the *Natyashastra*. The GTIM system that is being presented here has recognized the role of these *swaras*. They are defined as *Anu-Anuvadi swaras*. So, if the identity element is *swara* 'sa' then the *swaras*, 're'/'kre' and 'ni'/'kni' are recognized as *Anu-Anuvadi swara* of 'sa'. From the musical point of view, there exists a '*Shadja-Rishabh Bhava*' between *swara* 'sa' and *swara* 're' as well as between *swara* 'sa' and *swara* 'ni' there exists the inverse *Shadja-Rishabh Bhava*. This results in a very interesting calculus of *Ragas*.

Raga Structure for Computation

We already developed a formal structure for *Raga* in the chapter dedicated to the characterization of *Raga*. Now as an extension to that for further detailing, we can develop a formal structure suitable for *Raga* calculus. In the GTIM system, we can define a *Raga* within a *Gana* system as an abstract structure with the help of this understanding. Accordingly, a *Raga* has one *Vadi swara*, it has two *Samvadi swaras*, two *Anuvadi swaras* and two *Anu-Anuvadi swaras*. *Samvadis, Anuvadis* and *Anu-Anuvadis* bring in further detailing of the original structure. These are derivable from the *Vadi swara* by application of the set of generative laws GL as discussed earlier.

At a very basic- seed level a *Raga* is made up of seven *swaras*, which in traditional terminology is called '*Sampurna*' *Raga*. Each of these seven *swaras* has a specific and well-defined role, status and character. Broadly in a *Raga,* there has to be a *Vadi swara*, a pair of *Samvadis* (traditionally only stronger *Samvadi* is recognized as a *Samvadi swara*), a pair of *Anuvadis* and a pair of *Anu-Anuvadis* as a basic requirement. A few more components will be discussed later on at the appropriate place. Since each *swara* in a *Raga* has certain status when there is a pair of *Samvadis* for instance, then we need to define the status of both the *Samvadis*. The status of *swaras* in all the above-mentioned pairs of *swaras* as *Samvadis, Anuvadis,* and *Anu-Anuvadis* is decided by the three important laws that are already discussed. These laws are, first the law of *Nitya swaras*, secondly, the law of co-existence of *swaras* and thirdly, the law of harmonic strength of *swaras*. Whenever we have to decide the status of *swaras* that are competing with each other, then these laws should be applied in the same priority order.

So, let us represent a *Raga* as follows in the context of *Shadja Gana*. R = {*Vadi, Samvadis, Anuvadis, Anu-Anuvadis*}

R = {< 0, 0>, <-3, 3 >, < -2, 2>, < -1, 1>}

R = {< 'sa', 'sa'>, < 'pa', 'ma'>, < 'dha', 'ga'>, < 'ni', 're'>}

R = {['sa'], ['pa', 'ma'], ['dha', 'ga'], ['ni', 're']}

R stands for a *Raga*. Currently, we are discussing the case where *Vadi* is a *swara* 'sa'. Always there will be only one *Vadi swara* in a *Raga* because it is a sort of identity element.

There is a pair of *swaras* called *Samvadis* made up of *swara* ‘ma’ and ‘pa’. Since there are two *Samvadis* and their status has to be defined by applying the above-mentioned laws. Since both of them are *Nitya swaras* and also have an equal relationship with the *Vadi* ‘sa’ as per the law of coexistence of *swaras*, both the *swaras* have equal status as per the first two laws but as per the law of harmonic strength, the *swara* ‘pa’ is stronger than the *swara* ‘ma’ and therefore, ‘pa’ becomes the ‘primary’ *Samvadi* and ‘ma’ becomes secondary *Samvadi*. So, we can represent now this ordered pair of *Samvadis* as [‘pa’, ‘ma’]. The first member in this square bracket will be treated as a primary *Samvadi* and the second member is a secondary *Samvadi*. The secondary *Samvadi* is also termed *Anya Samvadi* in the GTIM.

Similarly, there are pairs of *Anuvadis* and *Anu-Anuvadis*. The status of the member *swaras* in these cases can be decided by applying the above-mentioned three laws as done earlier in the case of *Samvadis*. Therefore, in the pair of *Anuvadis* <‘dha’, ‘ga’>, none of the members belongs to *Nitya swara*, so the first law is not applicable. None of the members has a relationship with the *Vadi* ‘sa’ *swara* as per the law of coexistence of *swaras*. So, the second law is not applicable here. As per the third law, ‘ga’ is stronger than the ‘dha’ and so ‘ga’ becomes the primary *Anuvadi* and ‘dha’ becomes the secondary *Anuvadi* in this *Raga* and can be represented as [‘ga’, ‘dha’].

Similarly in the case of the *Anu-Anuvadi* ordered pair <‘ni’, ‘re’>, the first law and the second law are not applicable. As per the third law ‘re’ is stronger and therefore it becomes the primary *Anu-Anuvadi* and ‘ni’ becomes the secondary *Anu-Anuvadi* and can be represented as [‘re’, ‘ni’]. So now the *Raga* structure represented within the *Gana* system will look as follows.

R = {[‘sa’], [‘pa’, ‘ma’], [‘ga’, ‘dha’], [‘re’, ‘ni’]}

For computational convenience, a slightly different representation is helpful while writing a computer program and therefore, *Raga* is represented as a ‘mega list that is a list of lists as follows:

R = [[‘ma’], [‘ni’, ‘re’], [‘dha’, ‘ga’], [‘pa’], [‘sa’]]

The braces are removed and replaced by the square brackets because it is helpful to process the *Raga* structure as a list. The list of *Vadi swara* is placed as a list of single elements at the end. The primary *Samvadi swara* is as a single-element list that is placed second to last. The secondary *Samvadi swara* is placed in a separate list from the first list. This is necessary because the role of a primary *Samvadi* and the secondary *Samvadi* are quite different in *Raga* rendering though their status is almost the same. This arrangement is helpful for computational processing. The second list in this representation is made up of *Anu-Anuvadi swaras* and the third list is made up of *Anuvadi swaras*. So, the final structure of a *Raga* is useful for computational purposes and looks as shown below.

Raga= [[secondary *Samvadi* or *Anya Samvadi*], [primary *Anu-Anuvadi*, secondary *Anu-Anuvadi*], [primary *Anuvadi*, secondary *Anuvadi*], [Primary *Samvadi*], [*Vadi*]].

The first list in the *Raga* description is called the '*Anya swara* list' because it carries information about various types of other *swaras* as well along with the *Anya Samvadi swara*. Eventually, the first list will have, apart from the *Anya Samvadi swara*, other *swaras* such as dual and triple forms of *swaras* in the *Raga* as well as other important *swaras.* That is the reason this list is called the *Anya swara* list. Positions of various *Anya swaras* in this list are as follows. The first *swara* is the *Anya Samvadi swara* as mentioned earlier. The second *swara* will be the dual form of *Madhyama swara*. It means if the *Raga* has 'ma' as a part of the main *swaras* of the *Raga* and if there is an additional form of *Madhyama swara* that is 'mat', then that additional form will be placed here. Similarly, if 'mat' is a part of the *Raga* as a main *swara* and 'ma' is required in the *Raga* as an additional *swara* then 'ma' will be placed in the second place in this list. If there is no such dual *swara* in the *Raga* then it will be kept empty but will be represented by the *swara* 'rkt'. The third place in this list is reserved for the 'ni'/ 'kni' *swaras* as per the requirement, otherwise, there will be a 'rkt' *swara*.

Then there is a second set of dual *swaras* that will be placed at positions from fourth to sixth places. These three places are reserved for the dual forms of 're', 'ga', 'dha' respectively. It means that the fourth place is reserved for 'kre'/ 're', the fifth place for 'kga'/ 'ga' and the sixth place for 'kdha'/ 'dha' respectively. The seventh place is reserved for the triple form of *Gandhar swara* which is normally 'bga' and the eighth place is for the triple form of *Nishad* which is 'bni'. In general, if there are no dual or triple forms of *swaras* in the *Raga* then these places will be kept empty and will be represented by 'rkt' *swara*. Even if a *Raga* does not have an *Anya Samvadi swara*, then that place will be represented by 'rkt' *swara*. Thus, the first list in the *Raga* description is very important because it carries dense *swara* information for the *Raga*. So, with this norm of representation, the *Raga* will look as follows. The *Raga* mega list will have the following constituents.

Raga= [[*Anya swara* (*Samvadi*)*,* dual *Madhyama,* dual *Nishad,* dual *Rishabha,* dual *Gandhara,* dual *Dhaivata,* Triple *Gandhar* (*Bharatas' Gandhar*)*,* triple *Nishad* (*Bharata's Nishad*)]*,* [primary *Anu-Anuvadi,* secondary *Anu-Anuvadi*]*,* [primary *Anuvadi,* secondary *Anuvadi*]*,* [Primary *Samvadi*]*,* [*Vadi*]].

The example of *Shadja Gana Raga* that we are discussing will look as follows. This is the basic or seed *Shadja Gana Raga* which may be termed *Shadja Gana Beeja Raga*.

R = [['ma', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ni', 're'], ['dha', 'ga'], ['pa'], ['sa']]

This *Beeja Raga* can have multiple variations possible as we replace the *Anuvadi or Anu-Anuvadi swaras*. Let's understand these possibilities and their computational foundations.

As already discussed in detail from the computational music point of view a *Raga* is represented symbolically by following steps. The steps are repeated here again for ease of understanding.

A *Raga* structure is explained in a step-by-step manner for *Shadja Gana Raga* as follows.

R = {*Vadi, Samvadis, Anuvadis, Anu-Anuvadis*}

R = {< 0, 0>, <-3, 3 >, < -2, 2>, < -1, 1>}

R = {< ‘sa’, ‘sa’>, < ‘pa’, ‘ma’>, < ‘dha’, ‘ga’>, < ‘ni’, ‘re’>}

R = {[‘sa’], [‘pa’, ‘ma’], [‘dha’, ‘ga’], [‘ni’, ‘re’]}

Eventually, we developed above discussed computational norm to represent a *Raga* for the ease of computation as follows and so the *Shadja Gana Beeja Raga* will look like as follows.

R = [[‘ma’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘re’, ‘ni’], [‘ga’, ‘dha’], [‘pa’], [‘sa’]]

As already discussed in details that SN7, SS7 and SS12 can be mapped onto each other and a correspondence is established among them. It is repeated here as a reference.

SS12= {[‘pa’], [‘kdha’, ‘dha’], [‘kni’, ‘ni’], [‘sa’], [‘kre’, ‘re’], [‘kga’, ‘ga’], [‘ma’, ‘mat]}

SS7 = {‘pa’, ‘dha’, ‘ni’, ‘sa’, ‘re’, ‘ga’, ‘ma’}

SN7 = {-3, -2, -1, 0, 1, 2, 3}

The above-mentioned *Raga* representation for *Shadja-Gana Ragas* has evolved out of this mapping. Using the norms developed in this chapter more detailed treatment can be given to the seed *Ragas* of each *Ganas* for generating variations. These variations may lead to the real *Ragas* eventually. The next few chapters will focus on various aspects of this process.

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CHAPTER 13

From the Seed I Grow- Variations on Seed *Ragas*

Introduction

Using the norms that are established in the previous chapter, we can explore the possibility of generating variations on the seed *Ragas*. The generic norm to represent a *Raga* is as follows.

Raga= [[*Anya swara* (*Samvadi*)*,* dual *Madhyama,* dual *Nishad,* dual *Rishabha,* dual *Gandhara,* dual *Dhaivata,* Triple *Gandhar* (*Bharatas' Gandhar*)*,* triple *Nishad* (*Bharata's Nishad*)]*,* [primary *Anu-Anuvadi,* secondary *Anu-Anuvadi*]*,* [primary *Anuvadi,* secondary *Anuvadi*]*,* [Primary *Samvadi*]*,* [*Vadi*]].

The example of *Shadja Gana Raga* that we already discussed in the previous chapter looks as follows. This is the basic or seed *Shadja Gana Raga* which may be termed as *Shadja Gana Beeja Raga*.

R = [['ma', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ni', 're'], ['dha', 'ga'], ['pa'], ['sa']]

This seed *Raga* can have multiple variations possible as we replace the *Anuvadi or Anu-Anuvadi swaras* and even *Anya Samvadi swara*. Let's understand these possibilities and their computational foundations.

Initially, let us generate variations on the *Shadja Gana Beeja Raga*. While generating variations we need to keep in mind certain constraints. For instance, a *Vadi swara* cannot be changed in the *Raga* because it is the main *swara* of the *Raga*. The whole *Raga* rendering is dependent on the *Vadi swara*. *Samvadi, Anuvadi and Anu-Anuvadis* can be changed by preserving the correspondence among SN7, SS7 and SS12 sets as defined in the previous chapter. The dual *swaras* and triple *swaras* have different norms which will be discussed at appropriate places. So currently we are looking for variations on the basic seed *Raga* of *Shadja Gana*. Presently we are not looking for the dual-*swara* forms in the *Raga*. However, though the process appears simple, it is not the case. It involves complex dynamics of the application of laws of musical logic (LML). This dynamic is also guided by many traditional norms implicit in Indian musical tradition. First, let us explore the possibility of changing the *Samvadi*. Here *swara* ‘pa’ is a *Samvadi* or primary *Samvadi*. But since it is the strongest *Samvadi*, it cannot be replaced. We can replace it with another *Samvadi* ‘ma’ but in that case ‘pa’ has to be completely omitted from the *Raga* because since it is stronger than ‘ma’ it will overshadow ‘ma’. This is possible but currently, we are not looking for variations by omitting *swaras* from the *Raga*. That will be done while generating *Shadava* and *Oudava Ragas*. So, as it stands, in this case, *Samvadi* cannot be replaced. Now let us find out about replacing the *Anya Samvadi*. It is ‘ma’ *swara*. It can be replaced by ‘mat’ *swara* due to the correspondence between SS7 and SS12. So, if we replace ‘ma’ with ‘mat’ then this *Raga* will look as follows.

R = [[‘**mat**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘re’, ‘ni’], [‘ga’, ‘dha’], [‘pa’], [‘sa’]]

This is a new valid *Raga*. Similarly, we can change the primary *Anuvadi swara* ‘ga’ in the base seed *Raga* by its corresponding *swara* in the SS12 set ‘kga’ and we will get one more valid variation. It is as follows.

R = [[‘ma’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘re’, ‘ni’], [‘**kga**’, ‘dha’], [‘pa’], [‘sa’]]

In the same fashion by changing the secondary *Anuvadi*, following two variations can be generated. As follows

R = [[‘ma’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘re’, ‘ni’], [‘**ga**’, ‘**kdha**’], [‘pa’], [‘sa’]] and

R = [[‘ma’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘re’, ‘ni’], [‘**kga**’, ‘**kdha**’], [‘pa’], [‘sa’]]

So far, we got four variations on the original *Beeja Raga* by just changing the primary and secondary *Anuvadi swaras*. Now by changing primary *Anu-Anuvadis* of each of these variations we get four more variations as follows.

R = [[‘**ma**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**kre**’, ‘ni’], [‘**ga**’, ‘**dha**’], [‘pa’], [‘sa’]]

R = [[‘**ma**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**kre**’, ‘ni’], [‘**kga**’, ‘**dha**’], [‘pa’], [‘sa’]]

R = [[‘**ma**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**kre**’, ‘ni’], [‘**ga**’, ‘**kdha**’], [‘pa’], [‘sa’]] and

R = [[‘**ma**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**kre**’, ‘ni’], [‘**kga**’, ‘**kdha**’], [‘pa’], [‘sa’]]

By changing the secondary *Anu-Anuvadi* we get following variations.

R = [[‘**ma**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**re**’, ‘**ni**’], [‘**ga**’, ‘**dha**’], [‘pa’], [‘sa’]]

R = [[‘**ma**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**re**’, ‘**ni**’], [‘**kga**’, ‘**dha**’], [‘pa’], [‘sa’]]

R = [[‘**ma**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**re**’, ‘**kni**’], [‘**ga**’, ‘**kdha**’], [‘pa’], [‘sa’]] and also, we get following variations.

R = [[‘**ma**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**re**’, ‘**kni**’], [‘**kga**’, ‘**kdha**’], [‘pa’], [‘sa’]]

R = [[‘**ma**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**kre**’, ‘**kni**’], [‘**ga**’, ‘**dha**’], [‘pa’], [‘sa’]]

R = [[‘**ma**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**kre**’, ‘**kni**’], [‘**kga**’, ‘**dha**’], [‘pa’], [‘sa’]]

R = [[‘**ma**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**kre**’, ‘**kni**’], [‘**ga**’, ‘**kdha**’], [‘pa’], [‘sa’]] and the last one as follows.

R = [[‘**ma**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**kre**’, ‘**kni**’], [‘**kga**’, ‘**kdha**’], [‘pa’], [‘sa’]]

So far, we have generated 16 variations of the *Shadja Gana Beeja Raga*, including the original. If we replace ‘ma’ by ‘mat in all the above 16 variations we get 16 more variations of the *Beeja Raga*.

The whole set of variations with mat as the *Anya swara* or *Anya Samvadi swara* is as follows.

R = [[‘**mat**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**kre**’, ‘ni’], [‘**ga**’, ‘**dha**’], [‘pa’], [‘sa’]]

R = [[‘**mat**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**kre**’, ‘ni’], [‘**kga**’, ‘**dha**’], [‘pa’], [‘sa’]]

R = [[‘**mat**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**kre**’, ‘ni’], [‘**ga**’, ‘**kdha**’], [‘pa’], [‘sa’]] and

R = [[‘**mat**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**kre**’, ‘ni’], [‘**kga**’, ‘**kdha**’], [‘pa’], [‘sa’]]

By changing the secondary *Anu-Anuvadi* we get following variations.

R = [[‘**mat**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**re**’, ‘**ni**’], [‘**ga**’, ‘**dha**’], [‘pa’], [‘sa’]]

R = [[‘**mat**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**re**’, ‘**ni**’], [‘**kga**’, ‘**dha**’], [‘pa’], [‘sa’]]

R = [[‘**mat**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**re**’, ‘**kni**’], [‘**ga**’, ‘**kdha**’], [‘pa’], [‘sa’]] and

R = [[‘**mat**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**re**’, ‘**kni**’], [‘**kga**’, ‘**kdha**’], [‘pa’], [‘sa’]]

R = [[‘**mat**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**kre**’, ‘**kni**’], [‘**ga**’, ‘**dha**’], [‘pa’], [‘sa’]]

R = [[‘**mat**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**kre**’, ‘**kni**’], [‘**kga**’, ‘**dha**’], [‘pa’], [‘sa’]]

R = [[‘**mat**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**kre**’, ‘**kni**’], [‘**ga**’, ‘**kdha**’], [‘pa’], [‘sa’]] and

R = [[‘**mat**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**kre**’, ‘**kni**’], [‘**kga**’, ‘**kdha**’], [‘pa’], [‘sa’]]

Thus, we have generated 32 variations of the *Beeja Raga* of *Shadja Gana*. These are the highest number of variations possible for any Gana.

Now let us take this discussion forward. Following are our standard representations assuming ‘sa’ as the *Vadi swara* for the *Shadja Gana*. It is repeated as follows for the convenience of readers.

SN7 = {-3, -2, -1, 0, 1, 2, 3} -Symbolic numerical representation.

SS7 = {‘pa’, ‘dha’, ‘ni’, ‘sa’, ‘re’, ‘ga’, ‘ma’} – seven *swaras* mapped on the above.

SS12= {[‘pa’], [‘kdha’, ‘dha’], [‘kni’, ‘ni’], [‘sa’], [‘kre’, ‘re’], [‘kga’, ‘ga’], [‘ma’, ‘mat]} – mapping on the SS12 set.

Seed *Shadja Gana Raga* = [[‘ma’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘re’, ‘ni’], [‘ga’, ‘dha’], [‘pa’], [‘sa’]]. -*Raga* representation for computational processing.

Now instead of ‘sa’, if we consider ‘ga’ as the *Vadi swara* for the *Gandhara Gana* then above representation will change and look like as follows.

SN7 = {-3, -2, -1, 0, 1, 2, 3} -Symbolic numerical representation

SS7 = {‘ni’, ‘sa’, ‘re’, ‘**ga**’, ‘ma’, ‘pa’, ‘dha’} – Seven *swaras* mapped on the above with ‘ga’ as a *Vadi swara* or as the identity element.

SS12= {[‘kni’, ‘ni’], [‘sa’], [‘kre’, ‘re’], [‘kga’, ‘ga’], [‘ma’, ‘mat], [‘pa’], [‘kdha’, ‘dha’]} -Mapping on the SS12 set

Let us consider 0 as an identity element in SN7 that stands for *swara* ‘ga’ now. So, in the computational calculus of *Raga* generation process for *Gandhar Gana* the *swara* ‘ga’ plays a role of an identity element or the *Vadi swara*.

From SN7 following ordered pairs can be generated for *Gandhar Gana*. Let us take the numbers whose absolute values are equal and generate the ordered pairs as follows.

|-1|=|1| have the same absolute value that stands for ‘re’ and ‘ma’ respectively. We can put them together as an ordered pair. So <‘re’, ‘ma’> but it also means that <[‘kre’, ‘re’], [‘ma’, ‘mat’]> because ‘re’ stands for [‘kre’, and ‘re’] and ‘ma’ stands for [‘ma’, ‘mat’] in the set SS12. In the same fashion |-2|=|2| and therefore < ‘sa’, ‘pa> are validated. In the similar manner, |-3|=|3| and so <‘ni’, ‘dha’> and <[‘kni’,

'ni'], ['kdha', 'dha']> are the valid ordered pairs. This pairing is also significant and important from musical point of view. By just shifting 'ga' to identity place and by making it a *Vadi swara* we get a pair of *Samvadis, Anuvadis* and *Anu-Anuvadis* for the *Gandhar Gana*. Seed *Ragas* for the *Gandhara Gana* can be generated with this. By following same approach, seed *Ragas* with variations can be generated for all the other *Ganas*.

In reference to SS7, we have seven *swaras* as the main *swaras* of the *Shadja Gana* but if we map them on the SS12 then we have 12 *swaras* as the main *swaras* for *Shadja Ganas*. If we want to consider each *swara* as a *Gana swara* then seven *Ganas* are possible from SS7. But we are mapping SS7 onto SS12 so actually 12 *Ganas* are possible. Logic will work as follows. *Shadja Gana* is already established. There will be two *Ganas* for 're', 'ga', and 'dha' *swaras* each. Accordingly, we have *Rishabha Gana* and *Komala Rishabha Gana, Gandhara Gana* and *Komala Gandhara Gana, Dhaivata Gana* and *Komala Dhaivata Gana*. Apart from that 'ma' and 'pa' *swaras* will have only one *Gana* each as *Madhyama Gana* and *Panchama Gana* respectively. The remaining *swaras* 'ni', 'kni', and 'mat' *swaras* are not considered as *Raga* generating *swaras* and there are no *Gana Ragas* for them as already discussed in the earlier chapters. So, in total, there are nine *Ganas* or *Nava Ganas*. Each of these *Ganas* specifications is discussed in the following paragraphs in brief.

Here it is worth mentioning that for each *Gana Raga,* the main *swara* is treated as a *Vadi swara*. But for a *Vadi swara* always there is a possibility of two valid *Samvadis*. Thus, each *Gana* has two variations based on *Samvadis*. *Vadi* always has a *Samvadi* based on the *Shadja-Panchama Bhava* which is normally considered as the strong pair of *Vadi-Samvadi*. The other *Samvadi* is based on the *Shadja-Madhyama Bhava*. This is a relatively not-so-strong relationship as considered in the previous one. The third *Samvadi* is technically possible by applying the *Shadja-Teevra Madhyama Bhava* though traditionally it is not considered as a valid *Samvadi*. In the GTIM system, the third *Samvadi* is considered as a valid *Samvadi* in certain cases but it will never have the status of the main *Samvadi* or the primary *Samvadi*. Thus, as a result, we get two variations of the original seed *Raga* for a *Gana*. However, there exist very interesting dynamics between *swaras* based on their harmonic strength. This will become clearer when we discuss all the *Ganas*.

Seed *Raga* Variations for *Ganas*

A detailed description of the *Shadja Gana* seed *Raga* variations is already provided and therefore it is not repeated here. Following is the formal description of *Ganas* starting with the *Panchama Gana* and ending with the *Komal Dhaivata Gana*. All the possible variations of seed *Ragas* for each *Gana* are not provided because as thoroughly discussed in the above paragraphs, such variations can be computationally generated. Thus, only the original *Gana Raga* is mentioned with certain salient characteristics that are important to generate variations.

Panchama Gana:

Seed *Panchama Gana Raga* = {‘re’, ‘ga’, ‘ma’, ‘**pa**’, ‘dha’, ‘ni’, ‘sa’} Pa is the *Vadi swara*.

Seed *Panchama Gana Raga* = [[‘re’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘ma’, ‘dha’], [‘ga’, ‘ni’], [‘sa’], [‘pa’]]

In this case ‘sa’ is the *Samvadi* of the *Raga* and *Anya Samvadi* is ‘re’ *swara*. Alternatively, ‘kre’ also can be in the place of ‘re’ as *Anya Samvadi swara*. So, with ‘pa’ and ‘sa’, *Vadi-Samvadi* combinations, 32 seed *Ragas* are possible. But interestingly, the other version of ‘pa’ *Vadi* and ‘re’ as *Samvadi* is not possible because as we know ‘sa’ is harmonically very strong *swara*. Secondly, *swara* ‘sa’ cannot be omitted from the *Raga* because ‘sa’ is a base *swara* or the tonic. Therefore ‘sa’ cannot be the *Anya Samvadi swara* in any case and as a result *Ragas* with ‘pa’ as *Vadi* and ‘re’ as *Samvadi* are not possible.

Madhyama Gana:

Seed *Madhyama Gana Raga* = {‘sa’, ‘re’, ‘ga’, ‘**ma**’, ‘pa’, ‘dha’, ‘ni’} Ma is the *Vadi swara*.

Seed *Madhyama Gana Raga* = [[‘kni’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘pa’, ‘ga’], [‘re’, ‘dha’], [‘sa’], [‘ma’]].

In this case ‘sa’ is the *Samvadi* of the *Raga* and *Anya Samvadi* is ‘kni’ *swara*. Here, ‘kni’ can be replaced by ‘ni’ *swara* to generate a few more variations. So, with ‘ma’ and ‘sa’, *Vadi-Samvadi* combinations sixteen seed Rags are possible. But interestingly, the other version of ‘ma’ *Vadi* and ‘kni’ as *Samvadi* is not possible because as we know ‘sa’ is harmonically very strong *swara.* Secondly, *swara* ‘sa’ cannot be omitted from the *Raga* because ‘sa’ is a base *swara* or the fundamental *swara*. Therefore ‘sa’ cannot be the *Anya Samvadi swara* and as a result such *Ragas* are not possible.

Gandhara Gana:

SS7 = {‘ni’, ‘sa’, ‘re’, ‘**ga**’, ‘ma’, ‘pa’, ‘dha’} Ga is the *Vadi swara*.

The seed *Gandhara Gana Raga* = {‘ni’, ‘sa’, ‘re’, ‘ga’, ‘ma’, ‘pa’, ‘dha’} is already discussed.

Seed *Gandhara Gana Raga* = [[‘dha’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘ma’, ‘re’], [‘pa’, ‘sa’], [‘ni’], [‘ga’]]. When variations are generated by computational processes on this seed *Raga*, we get 8 variations.

The seed *Gandhara Raga* has two possible versions. The first is as mentioned above has *swara* 'ni' as a *Samvadi* of the *Vadi* 'ga' *swara*. The other *Samvadi* is *swara* 'dha'. Dha also deserves to be the *Samvadi*. But since the relationship between 'ga' and 'ni' is achieved by the *Shadja-Panchama Bhava* and follows the law of co-existence of *swaras* very strongly this 'ga'- 'ni' relationship is relatively stronger. The other relationship of 'ga' - 'dha' is not so strong. To tackle these tricky dynamics of harmonic strength, in all the *Ragas* generated with 'ga' – 'dha' relationship, the *swara* 'ni' should be *Varjya* or weak in the *Raga* because it may become a problem for *swara* 'dha' to play the role of a *Samvadi*. The 'ni' *swara* will distract the impact of dha in every possible way. Therefore, in all such *Ragas* *swara* 'ni' should be replaced by *swara* 'kni'. So, in all the *Ragas* of *Gandhara Gana* when 'dha' is a *Samvadi swara*, the 'ni' swara will be a *Varjya swara* or will be replaced by 'kni' *swara*. This puts a restriction on the generation process of 'ga' – 'dha' *Vadi -Samvadi Ragas*. So the original seed *Raga* for 'ga' –'dha' *Vadi-Samvadi Ragas* will be as follows.

SS7 = {'kni', 'sa', 're', '**ga**', 'ma', 'pa', 'dha'} Ga is the *Vadi swara*.

Seed *Gandhara Gana Raga* = [['kni', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['dha'], ['ga']].

Anya swara is 'kni' instead of 'ni' *swara*. So, on this basic structure variations can be worked out. The computational process results in 4 variations of this seed *Raga*.

So totally for *Gandhara Gana,* there are 12 variations possible- eight variations on *Raga* with 'ni' as a *Samvadi* and four variations from the *Raga* with 'dha' as a *Samvadi*. Each *Gana* has its structure and therefore, the number of variations will vary as per the *Vadi-Samvadi* pairs and the applicable criteria of laws of musical logic as it is being discussed.

***Rishabha Gana*:**

SS7 = {'dha', 'ni', 'sa', '**re**', 'ga', 'ma', 'pa'} Re is the *Vadi swara*.

SS12= {['kdha', 'dha'], ['kni', 'ni'], ['sa'], ['kre', 're'], ['kga', 'ga'], ['ma', 'mat], ['pa']}

So, seed *Rishabha Gana Raga* = {'dha', 'ni', 'sa', 're', 'ga', 'ma', 'pa'}

Seed *Rishabha Gana Raga* = [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['sa', 'ga'], ['ma', 'ni'], ['pa'], ['re']]

Rishabha as a *Vadi* and *Panchama* as a *Samvadi* is a strong combination of *Vadi* and *Samvadi* because 'pa' is a *Nitya swara*. There is another possible combination of 're' as a *Vadi* and 'dha' as a *Samvadi swara*. Due to the stronger harmonic strength, ‘pa’ will always be dominating as a *Samvadi*. But if we make ‘dha’ a *Samvadi swara* then we need to make the ‘pa’ a *Varjya swara*. However, if ‘pa’ is eliminated we cannot replace it with any other *swara*. In that case a *Raga* with ‘re’ as *Vadi* and ‘dha’ as a *Samvadi swara* will not be a *Sampurna-Sampurna Raga*. This is a special case when *Anya Samvadi* is not there. It will be *Shadava- Shadava Raga*. So, it will look as follows. As a result, there will be 16 *Ragas* with Re-Pa, *Vadi-Samvadi* combination while there will not be any *Sampurna- Sampurna Raga* with Re-Dha, *Vadi-Samvadi* combination. The description is as follows.

SS7 = {‘dha’, ‘ni’, ‘sa’, ‘**re**’, ‘ga’, ‘ma’, ‘rkt’} Re is the *Vadi swara*.

SS12= {[‘kdha’, ‘dha’], [‘kni’, ‘ni’], [‘sa’], [‘kre’, ‘re’], [‘kga’, ‘ga’], [‘ma’, ‘mat], [‘rkt’]}

So, seed *Rishabha Gana Raga* = {‘dha’, ‘ni’, ‘sa’, ‘re’, ‘ga’, ‘ma’, ‘rkt’}

Seed *Rishabha Gana Raga* = [[‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘sa’, ‘ga’], [‘ma’, ‘ni’], [‘dha’], [‘re’]]

Komala Gandhara Gana:

As already shown in the case of *Gandhara Gana*, in the same way *Komal Gandhara Gana Ragas* can be generated as follows.

SS7 = {‘kni’, ‘sa’, ‘re’, ‘**kga**’, ‘ma’, ‘pa’, ‘kdha’}

SS12= {[‘kni’, ‘ni’], [‘sa’], [‘kre’, ‘re’], [‘kga’, ‘ga’], [‘ma’, ‘mat], [‘pa’], [‘kdha’, ‘dha’]}

Seed *Komal Gandhara Gana Raga* = {‘kni’, ‘sa’, ‘re’, ‘kga’, ‘ma’, ‘pa’, ‘kdha’}

Seed *Komal Gandhara Gana Raga* = [[‘kdha’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘ma’, ‘re’], [‘pa’, ‘sa’], [‘kni’], [‘kga’]]

This is the first version of *Komala Gandhara Gana Raga* where ‘kni’ is *Samvadi* and the *Anya Samvadi* is ‘kdha’. The other version will have ‘kdha’ as a *Samvadi* but as *Anya swara* there will be *swara* ‘ni’ in place of ‘kni’ because if ‘kni’ is kept as *Anya swara* then it will unnecessarily interfere with the *Samvadi* ‘kdha’. The *swara* ‘ni’ will not interfere because ‘kga’ does not have a *Samvad Bhava* relationship with swara ‘ni’.

The computational processing generates 8 variations for *Komala Gandhara Raga* with ‘kni’ as a *Samvadi* and if the *Samvadi* is ‘kdha’ then there are four variations. So totally, there are 12 variations possible with *Komala Gandhara Gana* seed *Ragas*.

Komala Rishabha Gana:

Komala Rishabha Gana is another special case. In the basic structure of this *Gana,* there is one important difference. It has only 'kdha' as a *Samvadi swara*. The other place is empty because- originally there is supposed to be 'pa' swara but 'kre' and 'pa' relationship does not fit in either *Shadja-Panchama Bhava* or *Shadja-Madhyama Bhava*. Therefore, 'pa' cannot become *Anya Samvadi* of *Komal Rishabha*. Actually, 'kre' and 'mat' has a *Shadja-Madhyama Bhava* relationship but somehow 'mat' being harmonically very weak, it cannot be treated as *Anya Samvadi* and so the place for *Anya Samvadi* remains empty. As a result, there will be only one type of seed *Raga* for *Komala Rishabha Gana* and all the variations will be done on the same.

SS7 = {'kdha', 'ni', 'sa', '**kre**', 'ga', 'ma', 'rkt'} KRe is the *Vadi swara*.

SS12= {['kdha', 'dha'], ['kni', 'ni'], ['sa'], ['kre', 're'], ['kga', 'ga'], ['ma', 'mat], ['rkt']} Seed Komal Rishabha Gana Raga = {'kdha', 'ni', 'sa', 'kre', 'ga', 'ma', 'rkt'}

Seed Komal Rishabha Gana Raga = [['rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'],

['sa', 'ga'], ['ma', 'ni'], ['kdha'], ['kre']]

For *Komala Rishabha Gana* there are only four variations possible as per the computational processing.

Dhaivata Gana:

Seed *Dhaivata Raga* = {'ga', 'ma', 'pa', '**dha**', 'ni', 'sa', 're'} Dha is the *Vadi swara*.

Seed *Dhaivata Gana Raga* = [['re', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['pa, 'ni'], ['ma', 'sa'], ['ga'], ['dha']]. With main *Samvadi* Ga and *Anya Samvadi* Re.

In this case 'dha' is the Vadi and 'ga' is the *Samvadi* and 're' is the *Anya swara*. With this combination eight variations are possible. However, there is another version as follows that has 'dha' as *Vadi*, 're' as *Samvadi* and 'kga' as *Anya swara*. Here, again 'ga' cannot become the *Anya swara* because it has higher harmonic strength than the *Samvadi* 're'. It will interfere with *Samvadi* re. So 'ga' will not be there in this *Raga* and will be replaced by 'kga'. This version has four variations possible. So, in all, there will be twelve variations for *Dhaivata Gana Ragas*. This second version is represented as follows that has 're' as a *Samvadi* and 'kga' as the *Anya swara.*

Seed *Dhaivata Gana Raga* = [['kga', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['pa, 'ni'], ['ma', 'sa'], ['re'], ['dha']]. With main *Samvadi* Re and *Anya Samvadi* KGa.

Komala Dhaivata Gana:

Seed *Komal Dhaivata Raga* = {'kga', 'ma', 'pa', '**kdha**', 'ni', 'sa', 'kre'} KDha is the *Vadi*.

Seed *Komal Dhaivata Gana Raga* = [['kre', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'],

['pa, 'ni'], ['ma', 'sa'], ['kga'], ['kdha']].

This is the main seed version of *Komala Dhaivata Gana Ragas* that has 'kdha' as a *Vadi swara*, 'kga' as a *Samvadi swara* and 'kre' as an *Anya Samvadi swara*. By computation, we get eight variations on this version. The other version will look as follows.

Seed *Komal Dhaivata Gana Raga* = [['ga', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['pa, 'ni'], ['ma', 'sa'], ['kre'], ['kdha']].

This has 'ga' as an *Anya Samvadi swara* instead of 'kga' and the main *Samvadi* is 'kre'. *Ragas* like *Bhairava* will fall into this category. This version has four variations possible.

Thus, a brief description of all the nine *Ganas* is complete here. There are no *Ragas* with 'kni', 'ni', and 'mat' *swara* as *Vadis* and therefore there are no *Ganas* assigned for these *swaras*.

The analysis of known and popular *Ragas* provides many interesting insights into the phenomenon of *Ragas*- their origination, evolution and survival. As already mentioned, Indian music and the *Raga* system have originated from earlier *Moorchchhana* and *Taana* systems mentioned in Bharata Muni's *Natyashastra*. Even the *Sangeet Darpana* which is a medieval treatise on Indian music has mentioned the names of relevant *Moorchchhana* along with the description of *Ragas*. Musicians and musicologists used to correlate *Moorchchhana* and *Raga*, maybe in an intuitive way. But somehow there is no explicit reference to this connection in the literature. The GTIM system being discussed here is making that connection explicit. Rather it is more appropriate to say that the *Moorchchhana* and *Taana* system provides the foundational framework for the GTIM system.

In the above discussion on generating variations for all the *Ganas*, it was assumed that each seed *Raga* has seven *swaras* in *Aroha* and the same seven *swaras* in *Avroha* in reverse order. Interestingly, from each of these seed *Ragas* further variations are possible by deleting one or two *swaras* from *Aroha* and *Avroha* or either from *Aroha* or *Avroha*. If there are seven *swaras* in *Aroha* as well as *Avroha* then that *Raga* is called *Sampurna-Sampurna Raga*. That is the case in all the above examples. If the *Raga* has six *swaras* in *Aroha* and six *swaras* in *Avroha* then such *Ragas* are called *Shadava-Shadava Ragas*. If the *Raga* has five *swaras* in *Aroha* and five *swaras* in *Avroha* then such *Ragas* are called *Oudava-Oudava Ragas*. But in all such variations, few more permutations are possible. If the *Raga* has seven *swaras* in *Aroha* and six *swaras* in *Avroha* then such a *Raga* is called *Sampurna- Shadava Raga*. With this approach, the possible variations by permutation are as follows. In all, apart from the previously mentioned three variations viz. *Sampurna- Sampurna, Shadava-Shadava,* and *Oudava-Oudava Ragas*, there are six more variations. They are *Sampurna-Shadava, Shadava-Sampurna, Sampurna- Oudava, Oudava-Sampurna, Shadava-Oudava,* and *Oudava-Shadava Ragas*. So totally, there are nine such variations. In all these variations a particular *swara* is eliminated in *Aroha* then the same *swara* is normally eliminated or made *Varjya* in *Avroha*. That is the norm for *Shadava-Shadava Ragas* and *Oudava-Oudava Ragas* etc. However, there are *Ragas* where the *Varjya swaras* are completely different in *Aroha* and/ or *Avroha*. These are termed as 'Different *Varjya swara Raga*s' in the GTIM system. For each *Gana* such additional variations are possible. This aspect is discussed in more detail in chapter 15 dedicated to categories of *Ragas*. The formal structure of *Gana* is elaborately formulated in the previous few chapters and we know how to generate seed *Ragas* from the *Ganas*. The same thread of discussion continued in the present chapter focusing on the variations on the seed *Raga*. This is the initial formulation of the concept of *Raga*. Seed *Ragas* are in-between stages of the *Raga* generation process. *Seed Ragas* are not the real *Ragas*. They are hypothetical structures which need to be scrutinized for validity. They may be considered potential *Ragas*. After the application of the laws of musical logic (LML), some of the structures qualify as *Ragas* and others are rejected. The next few chapters will throw light on this process of validation as well as the characterization of *Ragas*.

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PART V

The Birth of *Ragas* (Pa)

CHAPTER 14

From Seed *Ragas* to Real *Ragas*

Introduction

While exploring the variations on *Ganas*, we had a glimpse of the dynamics of the process of *Raga* generation. The previous chapter provides more insights into the formal structure of the *Raga* and how it impacts the *Raga* generation process. In this chapter, it will be pertinent to take this generation process to the next level. The computational process of generation of *Ragas* goes through a quite complex and long process, checks, and validations. *Raga* is defined as a musical structure having one prominent *swara* called a *Vadi swara* which is also a *Gana swara*. Based on one of the *Shadja-Panchama Bhava* and *Shadja-Madhyama Bhava*, a *Raga* also has two *Samvadi swaras*. The stronger between them is called main or primary *Samvadi* and the other is called *Anya Samvadi*. Based on the two *Gandhara-Bhavas* two *Anuvadi swaras* are selected and out of these two, the stronger one *swara* is considered as a primary *Anuvadi* and the other one is considered secondary *Anuvadi*. Apart from *Vadi, Samvadi* and primary *Anuvadi swara* two more swaras are very crucial for the *Raga* structure. They are called *Anu-Anuvadis*. Both are selected by applying two *Rishabha- Bhavas*. Both of them are very close to the *Vadi swara* and therefore in all *krama* (sequential) phrases these *swaras* are invariably present. Therefore, from a structural point of view *Vadi, Samvadi, Anuvadi*, and *Anu-Anuvadi swaras* are the four core *swaras* of a *Raga* within the *Gana* system. Initially, while characterizing *Raga* only *Vadi swara* was mentioned in the formal structure along with the tonic, *Aroha, Avroha, Varjya swaras* and a set of laws of musical logic. The *Samvadis, Anuvadis, and Anu-Anuvadis* were not mentioned because they are generated by applying the laws of musical logic to the *Vadi swara*. As a first phase of the generative process, these swaras are manifested in seed Ragas. Now onwards other factors such as *Aroha, Avroha*, *Varjya swaras* etc. will be discussed while transforming seed Ragas into real Ragas. These are all structural characteristics of a Raga. Due to such structural characteristics of a *Raga,* the process of *Raga* generation becomes complex and challenging.

Computing Real *Ragas*

Following is a computational process of generating real *Ragas* from the seed *Ragas*. As a first step, the *Sampurna Ragas* having seven *swaras* are generated by computation by following the *Moorchchhana* logic. These are called seed *Ragas* as mentioned earlier. This is discussed already at length. These are not the real *Ragas*. This is just the generative base from which all the real *Ragas* of various categories are generated either by eliminating one or two *swaras* or by adding one or two or the required number of *swaras* in *Aroha* and *Avroha*. Some of the seed *Ragas* are preserved as they are if they fulfil the criteria of aural computational and musical logic.

The computational process of generating real *Ragas* from the pool of seed *Ragas* is quite complex and goes through many checks and validations. The entire process is governed by the aural logic or the laws of musical logic. There are twenty-two *shrutis/ swaras* in an octave as per Bharata Muni's paradigm. However, all the *shrutis* cannot be chosen as *Vadi swara* because some of them are very weak in terms of their harmonic strength. As already discussed, therefore, the set SS12 is taken as the base for selecting *Vadi swaras* and out of them nine *swaras* qualify as *Vadi swaras*. As repeatedly mentioned earlier, Ni, KNi and Mat *swaras* are not selected as *Vadi swaras*.

Once a *Vadi swara* of a *Raga* is chosen, it becomes easy to choose other *swaras*. Here it is worth mentioning that the aural logic for music does not validate *Ragas* by a random process. It validates *Ragas* by following stringent rules of musical or aural logic. These rules are based on certain aural laws, laws of harmonic ranking, laws of co-existence of *swaras*, and some other rules as mentioned in previous chapters. These laws are already discussed in detail in the chapter dedicated to them.

The summary of the step-by-step process of checking, validation and generation is as follows.

- Selection of a *Vadi swara* out of 9 select *swaras* from the set SS12.
- This leads to number of seed *Ragas* possible with the *Vadi* as a *Gana swara* by following the *Moorchchhana* logic as explained earlier.
- Checking and validation of an appropriate *Samvadi* by application of *Shadja-Panchama Bhava* or *Shadja-Madhyama Bhavas*.
- Checking and validation of all the *Anuvadis* of *Vadi swara* viz. (sa, [ga, kga, bga, kdha, bdha, dha]), both ascending and descending order by applying the *Shadja-Gandhar Bhava,* and *Shadja-Komal Gandhar Bhava*.
- Similarly, by applying *Shadja-Rishabha Bhava and Komal Rishabha Bhava* in ascending and descending order, one gets all the possible *Anu-Anuvadi swaras* such as (sa, [ckre, kre, bre, re, ni, kni, bni, dha]).

- There needs one more procedure to delete all the pairs who have same *swara*-forms such as (dha-kdha) etc. in them to avoid undesirable duplication of *Ragas*. This is done for all the above-mentioned *Ragas* as a double check because the *Moorchchhana* logic normally takes care of this.

All the above steps suggest that repetition of *swaras* or *swara*-forms is avoided at these initial stages of the generative process because the aim is to generate a set of base *Ragas* having seven *swaras* for the given *Vadi-Samvadi* pair. At later stages wherever required the *swara*-forms are introduced based again on certain criteria of aural computational logic. As far as possible the generative process is based on aural logic and not on the permutation and combinations.

Till this stage, for the given *Vadi-Samvadi* pair, all valid pairs of *Anuvadi swaras* and all valid pairs of *Anu-Anuvadi swaras* are checked and validated. So, for each combination of the above, six *swaras* are selected (*Vadi*-1, *Samvadi*-1, primary *Anuvadi*- 1, secondary *Anuvadi*-1, *Anu-Anuvadi*-1, and secondary *Anu-Anuvadi*-1). Now there is a need of validating one more *swara* called *Anya swara*. All the so far generated *swaras* are based on valid laws of aural logic such as *Shadja-Panchama Bhava, Shadja-Madhyama Bhava*, three types of *Shadja-Gandhar Bhavas,* four types of *Shadja-Rishabha Bhavas* that is inclusive of even *Vivadi Bhava*.

There are certain mandatory requirements for a set of *swaras* to be qualified as a *Raga*. One of them is that every *Raga* should have *swara* Sa as a member. Also, in a *Raga* one of the three *swaras*- Ma, Mat or Pa, should be there. The computational process checks for these criteria.

Thus, the generative process creates a pool of all valid *Ragas* (having seven *swaras* each) for the given pair of *Vadi* and *Samvadi*. After this complicated process of seed *Raga* generation, and validation, the process of *Raga* generation takes three major steps as follows.

- The first stage is of omitting one or two *swaras* from these seed *Ragas* by following certain rules of aural logic is done. Specifically, by following laws of musical inference, certain pair of *swaras* are omitted to generate *Oudava Ragas* and by omitting one of the *Anuvadis* or *Anu-Anuvadis* or by omitting *Anya Samvadi* one at a time, *Shadava Ragas* are generated from the seed *Ragas*. In the same manner *Oudava-Shadava, Shadava-Oudava* etc. variations are generated. This process is thoroughly discussed in the chapter dedicated to categories of *Ragas*.
- The second stage is of adding one or two more *swaras*-forms to these seed *Ragas* thus generated and validated by following certain rules of aural logic. In addition to that adding one or two more *swara*-forms to the

Oudava, Shadava etc. *Ragas* generated in previous stage. Specifically dual-forms of ma (mat, cmat), ni (kni, bni) are added as well as second set of dual forms of *swaras* such as re (kre, ckre, bre), ga (bga, kga) and dha (ckdha, kdha, bdha) are added following the laws of aural computational logic. These are called 'Augmented *Ragas'*. The detailed process is discussed in the chapter dedicated to Augmented *Ragas*.

- Similarly, by applying the laws of musical logic some of the seed *Ragas* are selected that fulfil the criteria of these rules. They are preserved as seven *swara Ragas* because they follow the aural musical logic. Other seed *Ragas* are not considered as valid *Ragas*.

As a result, all the valid *Ragas* are generated. All these valid *Ragas* are unique *Ragas* that fulfil the criteria of aural logic. Still, further analysis suggests that though there is no repetition of *Ragas* in the generated pool of all possible valid *Ragas*, there are few *Ragas* that compete with each other in various ways. Though the above process takes care of competing *Vadi-Samvadi* pairs, there are other possibilities for competing *swaras* as well. Given the same set of *swaras* in two *Ragas*, a *Vadi* may compete with the *Anuvadi* of the other similar *Raga* or a *Vadi* may compete with the *Anu-Anuvadi swaras* of the other *Raga*. The dynamics of the evolutionary process weed out the weaker *Ragas* in such a competition. To sort out such cases, in the computational generative process, one more screening of *Ragas* based on certain criteria is necessary. After that, the final set of valid *Ragas* in the GTIM is established. The process of eliminating competing *Ragas* is described briefly in the following chapters and there is a separate section dedicated to this process that explains the process of elimination with examples.

Raga **Generation Process: Few Rules of Thumb**

The above sections unfold the dynamics of deep-level computational processes followed in the *Raga* generation process. In the following few sections, it will be pertinent to take this generation process to the operational level where certain heuristics or rules of thumb become handy to generate *Ragas*. This is discussed with concrete examples and a few tables are provided that can be used as ready references to execute the process. Take the case of how to generate *Ragas* from the *Gandhar Gana* for instance. For *Gandhar Gana* the *Vadi swara* is Ga. Initially, multiple variations can be generated as seed *Ragas* for this purpose. Out of these seed *Ragas,* certain variations may not qualify and will be rejected. Others will be treated as valid real *Ragas*. The process of rejection and selection will go through many cycles. So let us understand the dynamics in this case. For Ga as a *Vadi,* there are two possible *Samvadis*- by the law of *Shadja-Panchama Bhava* Ni is the *Samvadi* and by the law of *Shadja-Madhyama Bhava swara* Dha is the other possible *Samvadi*. In this sense, they are the competing *Samvadis*. It means these same *swaras* in two *Ragas* with *Vadi* Ga are present and both these candidates'

Samvadis are also part of it then which one is to be selected as a *Samvadi* of the *Raga*? There can be two different *Ragas*, one having Ni as *Samvadi* and the other having Dha as *Samvadi*. But in that case, they become two competing *Ragas*. Another issue is whether can both such *Ragas* co-exist. In reality one of them survives and the other gets discarded over some time as a part of the natural evolutionary process. After analysis of such cases and computer simulation, it was found that there are certain norms or rules of aural musical logic that guide this process. In the above case the *Raga* with Ni as a *Samvadi* survives. For the selection of real *Ragas* from the seed *Ragas* these rules are very important. These rules were briefly touched upon in previous chapters but here a more detailed explanation is provided.

Rule 1: If one of the *Samvadi swara* belongs to the category of *Nitya swaras* and the other competing *Samvadi swara* is a regular *swara* (non-*Nitya*) then the *Raga* with the *Nitya swara* as a *Samvadi* will stay. It means if there is a competition between Pa and Dha as *Samvadi* for instance, then a *Raga* having Pa as a *Samvadi* will win.

Rule2: If both the competing *Samvadis* do not belong to the category of *Nitya swaras* (i.e., Sa, Pa, or Ma) then the *Raga* having the Sa-Pa *Bhava* between *Vadi* and *Samvadi* will win.

Rule3: If both the *Samvadis* belong to the category of *Nitya swaras* then the *Raga* with the *Vadi* having *Shadja-Panchama Bhava* with the *Samvadi* will survive. This is a special case of the Rule2.

These three rules decide the fate of a *Samvadi swara*. In the above case where Ga is the *Vadi* and Ni and Dha are competing *Samvadis* then Ni will win because the Ga-Ni relationship is a *Shadja-Panchama Bhava*. Therefore, in general, for any *Raga*, the following pairs of *Vadi-Samvadi* become important: KRe-KDha, Ga-Ni, KGa-KNi, Dha-Ga and KDha-KGa. These pairs do not have *Nitya swaras* as a member. It also means that if Ga-Dha is the *Vadi-Samvadis* of a *Raga* then the *swara* Ni will not be there in that Raga though KNi can be there. The same is the case for the following pairs: KRe-Mat where Mat does not qualify as a *Samvadi* being very low on the harmonic strength scale, so such a *Raga* will not exist, KGa-KDha- KNi will not be there but Ni can be there, Dha-Re where Ga will not be in *Raga* but KGa can be there and in the case of KDha-KRe the *swara* KDha will not be there but Dha can be there in the *Raga*. The best example of the last case is *Raga Bhairava* where *Vadi* is KDha and *Samvadi* is KRe. In this Raga, KGa is not there but Ga is there. Interestingly, Ga is quite strong harmonically but KDha and KRe both being emotive *swaras* their association is quite strong. The following table will give a clear idea about the above-mentioned dynamics. The author has arrived at these tables after lots of explorations, analysis and testing of existing *Ragas* through simulations.

Before going through these tables, it is important to keep in mind that once the *Vadi swara* of the *Raga* is decided, the possible *Samvadis*, possible *Anuvadis* and the possible *Anu-Anuvadis* are established. All these possibilities are based on the aural logical laws which are mentioned in the following table.

Bhava	***Swara***
Shadja-Panchama Bhava	*Samvadi swara*
Shadja-Madhyama Bhava	*Samvadi swara*
Shadja-Teevra-Madhyama Bhava	Optional *Samvadi swara*
Shadja-Gandhara Bhava	*Anuvadi swara*
Shadja-Komal-Gandhara Bhava	*Anuvadi swara*
Shadja-Dhaivata Bhava	*Anuvadi swara*
Shadja-Komal- Dhaivata Bhava	*Anuvadi swara*
Shadja-Rishabha Bhava	*Anu-Anuvadi swara*
Shadja-Komal-Rishabha Bhava	*Anu-Anuvadi swara*
Shadja-Nishada Bhava	*Anu-Anuvadi swara*
Shadja-Komal- Nishada Bhava	*Anu-Anuvadi swara*

Thus, the positions of *swaras* are fixed in the matrix of a *Raga* and the computational generative process makes choices based on the aural laws or *Bhavas*.

Computing *Samvadis*

Following table can be used as a ready reference to see which competing *Samvadi swara* will survive and which s*waras* will be discarded in the given situation. It also shows which *swaras* are accepted optionally and what are the possible weak *swaras* or *swaras* that can be made *Varjya swaras* in the given context of *Raga* generation process.

Vadi	**Main *Samvadi***	***Anya Samvadi***	**Occasionally Acceptable *Anya (Samvadi) Swara***	***Varjya* or Weak *swara***
Sa	Pa	Ma	Mat	-
Sa	Ma	-	Mat	Pa

Table to be continued

Pa	Sa	Re	KRe	-
Ma	Sa	KNi	Ni	-
Ga	Ni	Dha	KNi	-
Ga	Dha	-	KNi	Ni
Re	Dha	-	Mat	Pa
Re	Pa	Dha	KDha	-
KGa	KNi	KDha	Dha	-
KGa	KDha	-	Dha	KNi
KRe	KDha	-	Mat	-
Dha	Ga	Re	KGa	-
Dha	Re	-	KGa	Ga
KDha	KGa	KRe	Ga	
KDha	KRe	-	Ga	KGa

Few other norms need to be remembered as well.

- *Samvadi* cannot be completely eliminated from the *Raga*.
- *Samvadi* can be *Ardha-Varjya swara*, means it can be eliminated either from *Aroha* or *Avroha.*
- Main *Samvadi* is either harmonically stronger with its competing *Samvadi* or it is stronger by the virtue of *Shadja-Panchama Bhava* relation with the *Vadi swara*.
- *Anya Samvadi* is a secondary *Samvadi* and naturally it has less important role in the *Raga* as compared to main *Samvadi swara*. So main *Samvadi* and *Anya Samvadi* are not exactly equivalent in terms of their function and role.
- If main *Samvadi* is completely *Varjya* in the *Raga* then the *Anya Samvadi* becomes the main *Samvadi* and in that case that *Raga* does not have an *Anya Samvadi swara*. However, there can be an *Anya Samvadi swara* by virtue of *Shadja-Teevra Madhyama Bhava* relation with the *Vadi swara* in

certain special cases.

A similar table is shown below for *Anuvadi swaras* of the *Raga*.

Computing *Anuvadis*

Vadi	**Primary *Anuvadi***	**Possible Secondary *Anuvadis***
Sa	Ga	Dha, KDha
	KGa	Dha, KDha
Pa	Ga	Ni, KNi
Pa	KGa	Ni, KNi
Ma	Re	Dha, KDha
Ma	KRe	Dha, KDha
Ga	Pa	Sa
Re	Ma	Ni, KNi
Re	Ni	Mat
Re	KNi	Mat
KGa	Pa	Sa
KRe	Ma	Ni, KNi
Dha	Ma	Sa
Dha	Sa	Mat
KDha	Ma	Sa
KDha	Sa	Mat

Anuvadi swaras are very important in the *Raga*. Some important norms for

Anuvadi swaras are as follows.

- *Anuvadi swaras* are considered as *Bhava swaras* in GTIM because they establish the mood of the *Raga* in various ways. Especially the primary *Anuvadi swara* is very important.
- If primary *Anuvadi* is completely *Varjya* in the *Raga* then the harmonically stronger between the secondary *Anuvadi swaras* takes its place as the primary *Anuvadi*.
- Another important norm is that the primary *Anuvadi swara* and the secondary *Anuvadi swara* should not be *swara*-forms of each other. For instance, it means Ga and KGa cannot be the primary *Anuvadi* and secondary *Anuvadi* respectively in any *Raga*.
- In a Raga at least one *Anuvadi swara* has to be there and that is considered as the primary *Anuvadi swara* of the *Raga*.
- Any of the *Anuvadis* can be *Ardha-Varjya* in the *Raga* and even both of the *Anuvadis* can be *Ardha-Varjya* in the *Raga*. Good example of this case is *Raga Bhimapalas*. *Bhimapalas* has Re and Dha as *PAnuvadi* and *SAnuvadi swaras* which are *Ardha-Varjya* in the *Raga* because both of them are *Varjya* in the *Aroha*.
- Both the *Anuvadi swaras* cannot be completely *Varjya* in the *Raga*.

A similar table for *Anu-Anuvadi swaras* is shown below.

Computing *Anu-Anuvadis*

Vadi	**Primary *Anu-Anuvadi***	**Possible Secondary *Anu-Anuvadis***
Sa	Re	Ni, KNi
	KRe	Ni, KNi
Pa	Ma	Dha, KDha
	Dha	Mat
	KDha	Mat
Ma	Pa	Ga, KGa
Ga	Ma	Re, KRe
	Re	Mat

Table to be continued

	KRe	Mat
Re	Sa	Ga, KGa
KGa	Ma	Re, KRe
	Re	Mat
	KRe	Mat
KRe	Ma	Ga, KGa
Dha	Pa	Ni, KNi
	Ni	Mat
	KNi	Mat
KDha	Pa	Ni, KNi
	Ni	Mat
	KNi	Mat

Certain important norms related to *Anu-Anuvadi swaras* are as follows.

- *Anu-Anuvadi swaras* being close to the *Vadi swara* they provide the lead or direction to the *Raga* rendering process.
- The primary *Anu-Anuvadi swara* is very important because many a times for *Samvadi-Vadi Meend*, the *Anu-Anuvadi swara* is used as a *landing swara*.
- If primary *Anu-Anuvadi* is *Varjya* in the *Raga* then the harmonically stronger between the secondary *Anu-Anuvadi swaras* takes its place as the primary *Anu-Anuvadi*. In a *Raga* at least one *Anu-Anuvadi swara* has to be there and that is considered as the primary *Anu-Anuvadi swara* of the *Raga*.
- Another important norm is that the primary *Anu-Anuvadi swara* and the secondary *Anu-Anuvadi swara* should not be *swara*-forms of each other. For instance, it means Re and KRe cannot be the primary *Anu-Anuvadi* and secondary *Anu-Anuvadi* respectively in a *Raga*.
- Any of the *Anu-Anuvadis* can be *Ardha-Varjya* in the *Raga* and even both of the *Anu-Anuvadis* can be *Ardha-Varjya* in the *Raga*.
- However, both the *anu-Anuvadis* cannot be completely *Varjya* in the *Raga*.

Probably this is the right place to discuss the norms for *Varjya swaras*. So, the following section is devoted to the description of the norms related to *Varjya* *swaras*. Eventually, this discussion will set a backdrop for the next chapter dedicated to *Raga* categories.

Computing *Varjya Swaras*

In brief, following norms are followed for generating *Varjya swara/s* in the *Raga*.

- Sa being the tonic of the scale cannot be made *Varjya*.
- *Vadi* being the main *swara* of the *Raga* cannot be made *Varjya*.
- *Samvadi* being the second important *swara* in the *Raga* cannot be made completely *Varjya* however, it can be *Ardha-Varjya* in the *Raga*. The best example of this case is *Raga Asavari* where KDha is a *Vadi* and KGa is the *Samvadi*. But KGa is *Varjya swara* in the *Aroha* of this *Raga* and it is used in the *Avroha*.
- Similarly, *Anuvadi swara* can be *Ardha-Varjya* in the *Raga*. Even both the *Anuvadis* can be *Ardha-Varjya* in the *Raga*. Well known example of this case is *Raga Bhimapalas*. It has Re and Dha as primary *Anuvadi* and secondary *Anuvadis* respectively. Both these *swaras* are *Varjya* in the *Aroha* of this *Raga*.
- Both the *Anuvadis* cannot be completely *Varjya* in the *Raga*.
- Same applies to *Anu-Anuvadi swaras*. *Anu-Anuvadi swara* can be *Ardha-Varjya* in the *Raga*. Both the *Anu-Anuvadis* can be *Ardha-Varjya* in the *Raga* but they cannot be completely *Varjya* in the *Raga*.
- Number of completely *Varjya swaras* in a *Raga* cannot be more than two *swaras*. If the number of *Varjya swara* exceeds then such *Ragas* are classified as *Prakirna Ragas*. For example*, Chatuswari Ragas* have three *Varjya swaras* and they are classified as *Prakirna Ragas*.
- There can be different *Varjya swaras* in *Aroha* and *Avroha*. It means if a *swara* X is *Varjya* in the *Aroha*, then there can be another *swara* Y that can be *Varjya* in the *Avroha*. A very good example of this case is of *Raga Bahar*. *Raga Bahar* has *swara* Re *Varjya* in the *Aroha* and *swara* Dha is *Varjya* in *Avroha*. There is another version of *Raga Bahar* where, *swaras* Re and Pa are *Varjya* in the *Aroha* and *swara* Dha is *Varjya* in *Avroha*. Now interestingly since in the first case of *Raga Bahar* there are only two *swaras Varjya*, this is classified as a regular *Raga*. However, in the second version of the *Raga Bahar* there are three *Varjya swaras* and so the second version is classified under the *Prakirna Ragas* in the GTIM.

From the above description of various norms and rules related to *Samvadi swaras, Anuvadi swaras, Anu-Anuvadi swaras* and the *Varjya swaras* it will be very interesting to know that if you know the *Vadi swara* of a *Raga* and its *Aroha* and the *Avroha* then you do not need any other information about the *Raga* to render it. Using the above-mentioned norms all the required information/ data related to *Raga* rendering can be computationally generated. This is the unique strength of the GTIM paradigm.

This chapter initially provided a broad overview of computational *Raga* generation process. Then it provided few rules of thumb to execute this process. This chapter thus, explains the significance of *Vadi, Samvadi, Anuvadis, Anu-Anuvadis* and finally *Varjya swaras* in *Raga* generation process. Complex and intricate relationships between and among *swaras* of the *Raga* result into the generation of the whole range of *Ragas.* To organize such a diverse range of *Ragas* is a tremendous task. *Nava Gana* system provides the best way to classify *Ragas* from generation point of view. A set of *Ragas* is generated by making few *swaras Varjya* from the seed *Ragas*. This also becomes a handy tool to categorize *Ragas*. The next chapter elaborates on how the concept of *Taana* from the *Natyashastra* is useful to generate and organize these *Ragas* in various categories based on the number of *Varjya swaras*. Indian musicians and musicologists are already aware about this scheme however; it is interesting to unfold the hidden logical and formal structure of this scheme. *Varjya Swaras* have important role in the *Raga* generation process. How variety of *Ragas* can be generated from the seed *Ragas* due to subtle but prominent impact of 'missing notes' or *Varjya Swaras* will be highly insightful.

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CHAPTER 15

The Music of Missing Notes - *Raga* Categories

Taana- A Precursor to the Categories of *Raga*

Traditionally, apart from the *Mela* system or *Thaata* system, *Ragas* are categorized based on the number of *swaras* used in the *Raga*. *Ragas* using seven or more *swaras* are called *Sampurna Ragas*. If a *Raga* uses six *swaras* then it is called *Shadava Raga*. If a *Raga* uses five *swaras* then such *Ragas* are called *Oudava Ragas* [Bhatkhande, V. N., 1998 second edition, pp. 6-8]. The GTIM tries to position the traditional system of categorization of *Ragas* in a logical perspective. As already discussed, the *Ganas* are the main nine classes of *Ragas* as per the GTIM. The categories of *Ragas* which are being discussed here are considered sub-classes. As it is already discussed in previous chapters, the *Gana* system for the generation and classification of *Ragas* is inspired by the concept of *Moorchchhana*. Similarly, the concept of *Taana* from the *Natyashastra* is the source of inspiration for the development of the scheme of categorization of *Ragas*. Therefore, the *Taana* system from the *Natyashastra* is briefly discussed here first.

Natyashastra gives a process of generating *Taanas* from the *Moorchchhanas*. It is briefly presented as follows with an example. *Uttaramandra Moorchchhana* which is the first *Moorchchhana* of the *Shadja Grama* is taken as an example to illustrate this process. *Natyashastra* shows how the *Taanas* of the *Uttaramandra Moorchchhana* are generated by eliminating one or two *swaras* from it. [Brihaspati, 1986, pp. 54-70]

The first *Moorchchhana* of the *Shadja Grama* is as follows.

Uttaramandra Moorchchhana = {sa, bre, ga, ma, pa, bdha, bni}.

The original *Moorchchhana* is called *Sampurna Taana* in the *Natyashastra*

because there are seven *swaras* in a *Moorchchhana*.

Shuddha Sampurna form of the *Taana* is: [sa, bre, bga, ma, pa, bdha, bni].

If one *swara* is deleted from the *Sampurna Taana* then the newly formed *Taana* is called *Shadava Taana*. The *Shuddha Shadava* form of the *Taana* is: [bre, bga, ma, pa, bdha, bni].

If two *swaras* are eliminated from the *Sampurna Taana* then *Oudava Taanas* are generated because now each *Taana* will have five *swaras*. The word *Oudava* means five. Thus, the *Shuddha Oudava Taana* of the above *Moorchchhana* is: [bre, bga, ma, bdha, bni].

The GTIM follows the same logic for the categorization of *Ragas*.

The process of generating *Ganas* is already discussed in previous chapters. When variations are worked out on original *Ganas* then the process leads to the generation of seed *Ragas*. In an earlier discussion, there was a mention of *Varjya swaras* but the consequences of eliminating *swaras* from the seed *Ragas* were not discussed in detail. By following the logic of *Taana* generation as mentioned in the *Natyashastra*, we can generate further variations on the seed *Ragas* by eliminating a few *swaras* from them. Applying the same logic is quite simple. If there are seven *swaras* in *Aroha* and seven *swaras* in *Avroha*, of a seed *Raga* then it is called *Sampurna-Sampurna* seed *Raga*. But if one or two *swaras* are omitted from it then the nomenclature changes. If one *swara* is omitted from the *Sampurna- Sampurna* seed *Raga* then it is called *Shadava-Shadava* seed *Raga* and if two *swaras* are omitted then it is called *Oudava-Oudava* seed *Raga*. But this process of elimination is not random. There are certain norms based on the logic of music. The *Nava Gana* system can be further developed by incorporating the concepts of *Sampurna-Sampurna, Shadava-Shadava, Oudava-Oudava* etc. categories as sub-classes of *Ganas* into the system. As it stands, any *Raga* in its original form has seven *swaras* in the *Aroha* and seven *swaras* in the *Avroha* and therefore, it belongs to the *Sampurna-Sampurna* category of *Ragas*. In each *Gana,* all the original *Ragas* are the *Sampurna-Sampurna Ragas*. There is one exception to this called Special *Shadava-Shadava Ragas* and that will be discussed later on at the appropriate place.

Computational Dynamics of Categorization

In the *Sampurna-Sampurna* category of *Ragas,* there are no *Varjya swaras*. This is a zero *Varjya swara* category of *Ragas*. While in other categories such as *Shadava- Shadava* or *Oudava-Oudava* etc. categories one or two *swaras* are *Varjya*. There exists certain dynamics to decide which *swara/s* to be made *Varjya* because eliminating a *swara* from the original seed *Raga* is not so simple. Certain rules of thumb for *Varjya swaras* are already discussed in the previous chapter. They come in handy to achieve categorization.

For simple *Shadava-Shadava Ragas* one *swara* can be made *Varjya* from both-*Aroha* and *Avroha* but it is not done randomly. *Swaras* with certain statuses are made *Varjya* due to specific reasons. Analysis of existing *Ragas* suggests that only certain types of *swaras* can be made *Varjya*. These *swaras* are *Anya Samvadi*, primary *Anu-Anuvadi*, secondary *Anu-Anuvadi*, primary *Anuvadi*, and secondary *Anuvadi*. If one of them is made *Varjya* then the *Shadava-Shadava Raga* is generated from the *Sampurna-Sampurna* seed *Ragas*. *Samvadi* swara cannot be eliminated. If Samvadi is added to this list and then one of them is made *Varjya* only from the *Aroha* then it becomes *Shadava-Sampurna Raga* and if one of the above *swaras* is made *Varjya* from the *Avroha* then *Sampurna- Shadava Raga* is generated.

Norms for generating *Oudava Ragas* from the *Sampurna-Sampurna* seed *Ragas* are slightly different. For *Oudava Ragas*, two *swaras* are to be made *Varjya* from the *Sampurna* seed *Raga*. The process is a little complicated because there are many permutations and combinations of such pairs possible. For example, if the candidate pairs are, Ma-Ni, Ma-Kni, Mat-Ni, and Mat-KNi then which one to drop from the seed *Raga* is a quite tricky issue. Because if we select all the four options/ cases for *Varjya swara* then there will be four *Oudava Ragas* which are repetitions of each other. To avoid such a repetition, in the GTIM, laws of musical logic- LMLs are used as the elimination criteria. As it stands the laws of consonance such as *Shadja-Panchama Bhava, Shadja-Madhyama Bhava, Shadja-Gandhar Bhava, Shadja-Komal Gandhar Bhava, Shadja-Rishabha Bhava and Shadja-Komal Rishabha Bhavas* are used to decide about the *Varjya swara* pair for *Oudava Ragas*. Based on these laws Mat-Ni and Ma-Kni will be considered valid *Varjya* pairs for elimination for generating *Oudava Ragas*. This process may be elaborated with examples as follows.

Raga Bhupa and *Raga Deshakar* have the same five *swaras* as Sa, Re, Ga, Pa, Dha, and higher Sa. Both the *Ragas* can be generated from four different seed *Ragas*. They are as follows.

Seed *Raga* 1: Sa, Re, Ga, Ma, Pa Dha, Ni, higher Sa

Seed *Raga* 2: Sa, Re, Ga, **Mat**, Pa Dha, Ni, higher Sa

Seed *Raga* 3: Sa, Re, Ga, Ma, Pa Dha, **KNi,** higher Sa

Seed *Raga* 4: Sa, Re, Ga, **Mat**, Pa Dha, **KNi,** higher Sa

It means if from these four seed *Ragas* if we eliminate the above-mentioned pairs of candidates *Varjya swaras* respectively then we will have different versions of *Raga Bhupa* and *Raga Deshakar*. This is unwarranted due to repetition. To avoid such a repetition, instead of eliminating four pairs of *Varjya swaras* from four different seed *Ragas,* it is sufficient to eliminate only the Ma-KNi pair or Mat-Ni pair from two seed *Ragas*. The other two pairs- Ma-Ni and Mat-KNi are not considered valid because they do not adhere to the laws of consonance. The process is more complicated because in this example a set of four seed *Ragas* is considered without mentioning their *Vadi-Samvadis*. In reality, there are five such sets of four seed *Ragas* each. Four seed *Ragas* for Sa-Pa *Vadi-Samvadi*, four for Re-Pa *Vadi-Samvadi*, four for Ga-Dha *Vadi-Samvadi*, four for Pa-Sa *Vadi-Samvadi* and four for Dha-Ga *Vadi-Samvadi* seed *Ragas*. There are a total of 20 such seed *Ragas* from which *Raga Bhupa* and *Raga Deshakar* can be generated as far as the structure of *Ragas* is considered. But if we take into account the *Vadi-Samvadi* pairs alone then there is a set of four seed *Raga*s with Ga-Dha *Vadi-Samvadi* and there is another set of four seed *Ragas* for Dha-Ga *Vadi-Samvadi* pair. And from these two sets, *Raga Bhupa* and *Raga Deshakar* are generated. It is now clear why there is a need for such norms based on the laws of consonance. If these norms are not there then multiple versions of the same *Ragas* will be generated. For computational brevity, these norms are highly significant.

As a result of this discussion so far it may be said that the *Varjya swaras* can be decided based on laws of consonance as mentioned. Thus, the following pairs of *swaras* may be considered as candidate *Varjya swaras* to select appropriate *Oudava-Oudava Ragas* from the pool of available sets of seed *Ragas*. The pairs of *Varjya swaras* that adhere to the laws of consonance are as follows.

Sa cannot be a *Varjya swara* being the tonic of the *Saptaka* so it is not part of any pair.

The pairs based on *Shadja-Panchama Bhava* and *Shadja-Madhyama Bhava* are as follows: Pa-Re, Re-Pa, Re-Dha, Dha-Re, Ga-Ni, Ni-Ga, Ga-Dha, Dha-Ga, Ma- KNi, KNi-Ma, Mat-Ni, Ni-Mat.

Pairs based on *Shadja-Gandhar* and *Shadja-Komal Gandhar Bhava* are as follows: Re-Ma, Ma-Re, Re-Ni, Ni-Re, Ga-Pa, Pa-Ga, Ma-Dha, Dha-Ma, and Pa- Ni, Ni-Pa.

Pairs based on *Shadja-Rishabha Bhava* and *Shadja-Komal Rishabha Bhava* are as follows: Re-Ga, Ga-Re, Ga-Ma, Ma-Ga, Pa-Dha, Dha-Pa, Dha-Ni, Ni-Dha.

The ma-Pa pair is not considered valid because in a *Raga* Ma and Pa, both the *swaras* cannot be *Varjya* at the same time. They can be alternately *Varjya* in the *Aroha or Avroha*.

For *Oudava-Oudava Ragas* these norms work well but for other varieties of *Oudava Ragas* like *Oudava-Sampurna* and *Sampurna-Oudava* or *Oudava-Shadava* and *Shadava-Oudava Ragas* above pairs of *Varjya swaras* are valid but apart from them few more pairs of swaras can be used as *Varjya swaras*.

The pairs based on *Shadja-Panchama Bhava* and *Shadja-Madhyama Bhava* are as follows: Pa-Re, Re-Pa, Re-Dha, Dha-Re, Ga-Ni, Ni-Ga, Ga-Dha, Dha-Ga, Ma- KNi, KNi-Ma, Mat-Ni, Ni-Mat.

The additional pairs based on *Shadja-Panchama Bhava* and *Shadja-Madhyama Bhava* are KRe-KDha, KDha-KRe, KGa-KNi, KNi-KGa, KGa-KDha, KDha-KGa, and there are two special cases of Pa-KRe, KRe-Pa, and Ma-Ni, Ni-Ma pairs. The special case pairs follow the law of *Shadja-Teevra Madhyama Bhava* which is very rare and special.

Pairs based on *Shadja-Gandhar* and *Shadja-Komal Gandhar Bhava* are as follows: Re-Ma, Ma-Re, Re-Ni, Ni-Re, Ga-Pa, Pa-Ga, Ma-Dha, Dha-Ma, and Pa- Ni, Ni-Pa. These are the same as in the previous case of *Oudava-Oudava Ragas*. There are no additional pairs.

Pairs based on *Shadja-Rishabha Bhava* and *Shadja-Komal Rishabha Bhava* are as follows: Re-Ga, Ga-Re, Ga-Ma, Ma-Ga, Pa-Dha, Dha-Pa, Dha-Ni, Ni-Dha. Additional pairs based on *Shadja-Rishabha Bhava* and *Shadja-Komal Rishabha Bhava* are as follows: KRe-KGa, KGa-KRe, KDha-KNi, and KNi-KDha.

The process does not end here. When the process is implemented in the *AIRagaGen* system many interesting patterns unfolded during analysis. The dynamics of *Varjya swaras* are very interesting from a structural and computational point of view. From a structural point of view there exist certain patterns of elimination of these pairs of *swaras*. There are at least three groups of these patterns as listed below.

- *Anya Samvadi* and primary *Anu-Anuvadi, Anya Samvadi* and secondary *Anu-Anuvadi, Anya Samvadi* and primary *Anuvadi, Anya Samvadi* and secondary *Anuvadi* is the first group of *Varjya* pairs.
- The second group is primary *Anu-Anuvadi* and *primary Anuvadi swara*, primary *Anu-Anuvadi* and secondary *Anuvadi*, secondary *Anu-Anuvadi* and primary *Anuvadi swara*, secondary *Anu-Anuvadi* and secondary *Anuvadi*.
- The third group consists of primary *Anu-Anuvadi* and *Samvadi swara*, primary *Anuvadi* and *Samvadi*, secondary *Anu-Anuvadi* and *Samvadi swara*, secondary *Anuvadi* and *Samvadi swara* are some of the other pairs.

This third group is implemented when the *Samvadi swara* as a desired *Varjya swara* is harmonically stronger than the *Vadi* of the *Raga*. Similarly, *Anya Samvadi* and *Samvadi swara* pair also can be considered for making it a *Varjya* pair. In the case of *Oudava-Sampurna* and *Sampurna-Oudava Ragas* or *Oudava-Shadava* and *Shadava-Oudava Ragas, a* few more pairs can be added to the above list. The additional pairs would be primary *Anu-Anuvadi* and secondary *Anu-Anuvadi* pair, primary *Anuvadi* and secondary *Anuvadi* pairs.

In the case of *Ragas* like *Oudava-Shadava Ragas* and *Shadava-Oudava Ragas* we require to eliminate one *swara* from the *Shadava Ragas*. So, the above-mentioned laws of consonance can come in handy to take a call about the *Varjya Swara*. Also, the above-mentioned pairs of *Varjya swaras* can be used as a recipe for generating all types of *Oudava Ragas*.

Nine Categories of *Ragas* (*Nava Vargas* of *Ragas*)

The word category can be translated as '*Varga*' in Sanskrit. So, the nine categories of *Ragas* may be termed as '*Nava Vargas* of *Ragas*'. The above-mentioned theoretical dynamics of categorization of *Ragas* are explained with examples as follows. A detailed description of the process of categorization of the *Ragas* of all the *Ganas* is a huge task. It will occupy a large space. For the sake of brevity, a specimen description of the logic of categorization is provided here by taking an example from one *Gana*. *Gandhara Gana* is quite compact and therefore, to illustrate the dynamics of categorization the *Gandhar Gana* is chosen and the theoretical concepts are explained. The same logic and processes can be applied to other *Gana Ragas* for categorization. However, there is one category called Special *Shadava-Shadava Ragas* which is not possible in *Gandhara Gana*. So first the special case is discussed that is valid for *Shadja-Gana* and *Rishabha Gana* and then for the rest of the categories, examples are taken from *Gandhara Gana*.

Special *Shadava-Shadava Ragas*:

Apart from the regular *Shadava-Shadava Ragas*, there exists a category of *Shadava-Shadava Ragas* which is considered as '*Special Shadava-Shadava Ragas*' in GTIM. As we were discussing the *Raga* generation process earlier, we discussed the harmonic strength of various *swaras*. There are two particular instances where, in the case of *Sampurna-Sampurna Ragas*, when 'sa' is *Vadi* and 'ma' is *Samvadi* and when 're' is *Vadi* and 'dha' is *Samvadi*. In these two cases, there cannot be *Sampurna-Sampurna Ragas* for these pairs of *Vadi-Samvadis*. In the first case where 'ma' is a *Samvadi* swara, in that case, such a *Raga* cannot have 'pa' as *Anya Samvadi swara* because 'pa' is harmonically strong and it impacts the role of 'ma' as a *Samvadi*. So, in *Shadja Gana* when 'ma' is a *Samvadi*, there exists only *Shadava-Shadava Ragas* because *Anya Samvadi* 'pa' is made *Varjya* and the place is kept empty. For the same reason, in the case where 're' is *Vadi* and 'dha' is a *Samvadi*, the *swara* 'pa' cannot become the *Anya Samvadi* of the *Raga*, as the harmonic strength of 'pa' is more than the harmonic strength of 'dha' *swara*. Therefore, in *Rishabha Gana Ragas*, when *Samvadi* is 'dha', the *Ragas* will have only six *swaras*. Therefore, all such *Ragas* are considered special cases of *Shadava-Shadava Ragas*. The seed *Ragas* for this category are represented as follows.

Instance 1: Sa is a *Vadi* and Ma is a *Samvadi*.

The seed *Shadja Gana Raga* = {'sa', 're', 'ga', 'ma', 'rkt', 'dha', 'ni'} Computational Representation of the seed *Shadja Gana Raga* = [[**'rkt'**, 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['re', 'ni'], ['ga', 'dha'], ['ma'], ['sa']] –

In the above computational representation of a *Raga* with 'sa' *Vadi* with 'ma' as a *Samvadi,* the *Anya Samvadi* place is kept empty represented by 'rkt'.

Instance 2: Re is *Vadi* and Dha is Samvadi.

The seed *Rishabha Gana Raga* = {'re', 'ga', 'ma', 'rkt', 'dha', 'ni', 'sa'}

Computational Representation of the seed *Shadja Gana Raga* = [[**'rkt'**, 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['sa', 'ga'], ['ma', 'ni'], ['dha'], ['re']] –

In the above computational representation, with 're' as a *Vadi* and 'dha' as a *Samvadi*, the *Anya Samvadi* place is kept empty represented by 'rkt'.

When variations are worked out with computational processing, we get 16 variations in the first case of *Shadja Gana Ragas*, where 'sa' is *Vadi* and 'ma' is a *Samvadi*. In the second case of *Rishabha Gana Raga*, where 're' is the *Vadi* and 'dha' is a *Samvadi*, we get 8 variations of *Ragas*. Both cases are instances of 'Special *Shadava-Shadava' Ragas*.

Categorization of Regular *Ragas*

All the original seed *Ragas* with all their variations are called *Sampurna-Sampurna Ragas* because they have seven *swaras* in *Aroha* and seven *swaras* in *Avroha*. So now let us begin with the description of *Shadava-Shadava Ragas* for *Gandhara Gana* considering that as a representative example of all the regular *Ragas*.

The computational representation of the seed *Gandhara Gana Raga* is as follows:

Gandhara Gana Raga = [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']].

Shadava-Shadava Ragas:

If we want to generate *Shadava-Shadava Ragas* out of this original seed *Gandhara Gana Raga* then there are a limited number of possibilities. There are seven *swaras* and to make it a *Shadava* we need to eliminate one *swara* from it. First of all, *swara* 'sa' cannot be eliminated because it is a tonic and 'sa' is never a *Varjya swara* in the *Raga*. Similarly, *Vadi swara* cannot be eliminated from the *Raga* because it is the dominant *swara*. It defines the *Raga* so it cannot be deleted. The *Samvadi* cannot be deleted completely from the *Raga* because it is the second most dominant *swara* in the *Raga*. It can be deleted either in *Aroha* or *Avroha* but currently we are discussing regular *Shadava-Shadava Ragas*. So *Samvadi swara* cannot be deleted in this case. The remaining *swaras* can be eliminated one by one and we can generate four such variations from this seed *Raga* of the *Gandhara Gana*. These will be as follows.

Shadava-Shadava Gandhara Gana Raga = [['rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']]- *Anya Samvadi swara* 'dha' is eliminated.

Shadava-Shadava Gandhara Gana Raga = [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['rkt', 're'], ['pa', 'sa'], ['ni'], ['ga']]- Primary *Anu-Anuvadi swara* 'ma' is eliminated.

Shadava-Shadava Gandhara Gana Raga = [[‘dha’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘ma’, ‘rkt’], [‘pa’, ‘sa’], [‘ni’], [‘ga’]]- Secondary *Anu-Anuvadi swara* ‘re’ is eliminated.

Shadava-Shadava Gandhara Gana Raga = [[‘dha’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘ma’, ‘re’], [‘rkt’, ‘sa’], [‘ni’], [‘ga’]]- *Primary Anuvadi swara* ‘pa’ is eliminated.

These are the four variations of *Shadava-Shadava Ragas*. If we change *swaras* ‘re’, ‘dha’ and ‘ma’ to ‘kre’, ‘kdha’ and ‘mat’ by permutation many more variations will be generated. All these variations will be valid *Shadava-Shadava Ragas*. The computational process results in 20 such *Shadava-Shadava Ragas* for the *Gandhara Gana* with ‘ga’- ‘ni’ *Vadi-Samvadi* combination. For ‘ga’- ‘dha’ *Vadi-Samvadi* combination there are 8 possible *Shadava-Shadava Ragas*.

Oudava-Oudava Ragas:

As shown in the case of *Shadava-Shadava Ragas*, in the same way, the *Oudava-Oudava Ragas* also can be generated from the *Sampurna-Sampurna Ragas*. As we know the *Gandhara Gana* is represented as follows.

Computational representation of the seed *Gandhara Gana Raga* = [[‘dha’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘ma’, ‘re’], [‘pa’, ‘sa’], [‘ni’], [‘ga’]]

For generating *Oudava-Oudava Ragas* we need to delete two *swaras* from the original seed *Raga*. Again, as we know *swara*, ‘sa’, *Vadi swara*, and *Samvadi swaras* cannot be deleted from the original seed *Raga*. But there is one more constraint. From any *Raga*, *swaras* ‘pa’ and ‘ma’ cannot be eliminated at the same time. It means either of them has to be there in the *Raga*. Apart from that, we know that there are pairs of *Anu-Anuvadi swaras* and *Anuvadi swaras* in the *Ragas*. We cannot delete both the *swaras* of the pairs completely at any given time. That means both the *Anu-Anuvadis* and the *Anuvadis* cannot be omitted completely from the *Raga* at the same time. This is obvious because if both the *swaras* are deleted then there will not be any *Anu-Anuvadi* or *Anuvadi* in the *Raga*. So, taking into account these constraints, four variations for *Oudava-Oudava Ragas* can be generated as follows.

Seed *Gandhara Gana Raga* = [[‘dha’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘ma’, ‘re’], [‘pa’, ‘sa’], [‘ni’], [‘ga’]]

Oudava-Oudava variation on seed *Gandhara Gana Raga* = [[‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘rkt’, ‘re’], [‘pa’, ‘sa’], [‘ni’], [‘ga’]]- *Anya* and primary *Anu-Anuvadi* deleted.

Oudava-Oudava variation on seed *Gandhara Gana Raga* = [[‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘ma’, ‘rkt’], [‘pa’, ‘sa’], [‘ni’], [‘ga’]]- *Anya* and secondary *Anu-Anuvadi* deleted.

Oudava-Oudava variation on seed *Gandhara Gana Raga* = [['rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['rkt', 'sa'], ['ni'], ['ga']] - *Anya* and primary *Anuvadi* deleted.

Oudava-Oudava variation on seed *Gandhara Gana Raga* = [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 'rkt'], ['rkt', 'sa'], ['ni'], ['ga']]- Secondary *Anu-Anuvadi* and primary *Anuvadi* deleted.

From these variations, by changing *shuddha swara* into *vikruta swaras* we can generate many more variations. The computational process leads to 12 such variations for *Vadi-Samvadi*, 'ga' and 'ni' *swaras* pair. For the pair 'ga' and 'dha' *swaras* as *Vadi* and *Samvadi* we get 4 such *Ragas* by following the same process.

Till now, the number of *swaras* in the *Aroha and Avroha* were the same like seven *swaras*, or six *swaras* or five *swaras* but in the next group of categories, the number of *swaras* in *Aroha* and *Avroha* are different. Therefore, there is a need for representing *Ragas* where both, *Aroha* and *Avroha* are represented appropriately. Hence, in the following description, *Aroha, as well as Avroha,* are shown in *Raga* representation. Accordingly, the computational representation of the seed *Gandhara Gana Raga* is shown as follows.

Seed *Gandhara Gana Raga* = [[['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']], [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']]].

Shadava - Sampurna Ragas:

In this category of *Ragas*, the number of *swaras* in the *Aroha* will be six while in the *Avroha* there will be seven *swaras*. By following the above-mentioned approach, we can generate variations only on the *Aroha* part of the seed *Raga*. So, variations will be as follows.

Variations on the *Aroha* of the seed *Gandhara Gana Raga* = [[['**rkt**', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']], [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']]]- *Anya Samvadi* from *Aroha* is deleted.

Variations on the *Aroha* of the seed *Gandhara Gana Raga* = [[['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['**rkt**', 're'], ['pa', 'sa'], ['ni'], ['ga']], [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']]] – Primary *Anu-Anuvadi* from *Aroha* is deleted.

Variations on the *Aroha* of the seed *Gandhara Gana Raga* = [[['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', '**rkt**'], ['pa', 'sa'], ['ni'], ['ga']], [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']]]- Secondary *Anu-Anuvadi* from *Aroha* is deleted.

Variations on the *Aroha* of the seed *Gandhara Gana Raga* = [[['dha', 'rkt', 'rkt',

'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['**rkt**', 'sa'], ['ni'], ['ga']], [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']]]- Primary *Anuvadi* is deleted from the *Aroha*. Secondary *Anuvadi* is sa so it cannot be deleted.

Variations on the *Aroha* of the seed *Gandhara Gana Raga* = [[['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['**rkt**'], ['ga']], [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']]]- *Samvadi* is deleted from the *Aroha*.

***Sampurna- Shadava Ragas*:**

In this category of *Ragas*, the number of *swaras* in *Aroha* is seven while in the *Avroha* there will be six *swaras*. By following the above-mentioned approach, we can generate variations only on the *Avroha* part of the seed *Raga*. So, variations will be as follows.

Variations on the *Avroha of the seed Gandhara Gana Raga* = [[['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']], [['**rkt**', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']]]- *Anya Samvadi* from *Avroha* is deleted.

Variations on the *Avroha of the seed Gandhara Gana Raga* = [[['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']], [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['**rkt**', 're'], ['pa', 'sa'], ['ni'], ['ga']]] – Primary *Anu-Anuvadi* from *Avroha* is deleted.

Variations on the *Avroha of the seed Gandhara Gana Raga* = [[['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']], [['dha', 'rkt', 'rkt', 'rkt','rkt', 'rkt', 'rkt', 'rkt'], ['ma', '**rkt**'], ['pa', 'sa'], ['ni'], ['ga']]]- Secondary *Anu-Anuvadi* from *Avroha* is deleted.

Variations on the *Avroha of the seed Gandhara Gana Raga* = [[['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']], [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['**rkt**', 'sa'], ['ni'], ['ga']]]- Primary *Anuvadi* is deleted from the *Avroha*. Secondary *Anuvadi* is sa so it cannot be deleted.

Variations on the *Avroha of the seed Gandhara Gana Raga* = [[['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']], [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['**rkt**'], ['ga']]]- *Samvadi* is deleted from the *Avroha*.

So, five such variations are possible. One important factor needs to be mentioned here. In earlier, cases we have not deleted *Samvadi swara*. But here we are deleting *Samvadi swara* either from the *Aroha* or from the *Avroha*. This is allowed because *Samvadi* is not completely deleted from the *Raga*. So, it is valid to eliminate *Samvadi swara* either from *Aroha* or from *Avroha* but it cannot be deleted from both.

Oudava- Sampurna Ragas:

Oudava-Sampurna variation on seed *Gandhara Gana Raga* = [[['**rkt**', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['**rkt**', 're'], ['pa', 'sa'], ['ni'], ['ga']], [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']]]- *Anya Samvadi* and primary *Anu-Anuvadi* deleted from the *Aroha*.

Oudava-Sampurna variation on seed *Gandhara Gana Raga* = [[['**rkt**', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', '**rkt**'], ['pa', 'sa'], ['ni'], ['ga']], [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']]]- *Anya* and secondary *Anu-Anuvadi* deleted from the *Aroha*.

Oudava-Sampurna variation on seed *Gandhara Gana Raga* = [[['**rkt**', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['**rkt**', 'sa'], ['ni'], ['ga']], [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']]] - *Anya* and primary *Anuvadi* deleted from the *Aroha*. The secondary *Anuvadi* is sa therefore, such combinations are not possible.

Oudava-Sampurna variation on seed *Gandhara Gana Raga* = [[['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', '**rkt**'], ['rkt', 'sa'], ['ni'], ['ga']], [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['**pa**', 'sa'], ['ni'], ['ga']]]- Secondary *Anu-Anuvadi* and primary *Anuvadi* deleted from the *Aroha*. Primary *Anu-Anuvadi* is ma and primary *Anuvadi* is pa so only this option can be executed. Other combinations are not possible because the *swaras* ma and pa cannot be eliminated at the same time and the swaras cannot be eliminated from the *Raga*.

From these variations, by changing *Shuddha swara* into *Vikruta swaras* we can generate many more variations. The computational process leads to 12 such variations for *Vadi-Samvadi*, 'ga' and 'ni' *swaras*. For the pair 'ga' and 'dha' *swaras* as *Vadi* and *Samvadi* we get 4 such *Ragas* of the *Oudava-Sampurna* category.

Sampurna -Oudava Ragas:

Sampurna-Oudava variation on seed *Gandhara Gana Raga* = [[['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']], [['**rkt**', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['**rkt**', 're'], ['pa', 'sa'], ['ni'], ['ga']]]- *Anya* and primary *Anu-Anuvadi* deleted from the *Avroha*.

Sampurna-Oudava variation on seed *Gandhara Gana Raga* = [[['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']], [['**rkt**', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', '**rkt**'], ['pa', 'sa'], ['ni'], ['ga']]]- *Anya* and secondary *Anu-Anuvadi was* deleted from the *Avroha*.

Sampurna-Oudava variation on seed *Gandhara Gana Raga* = [[['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']], [['**rkt**', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['**rkt**', 'sa'], ['ni'], ['ga']]] - *Anya* and primary *Anuvadi* \ eleted from the *Avroha*.

Sampurna-Oudava variation on seed *Gandhara Gana Raga* = [[[‘dha’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘ma’, ‘re’], [‘pa’, ‘sa’], [‘ni’], [‘ga’]], [[‘dha’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘ma’, ‘**rkt**’], [‘**rkt**’, ‘sa’], [‘ni’], [‘ga’]]] - Secondary *Anu-Anuvadi* and primary *Anuvadi* deleted from the *Avroha*.

From these variations, by changing *Shuddha swara* into *Vikruta swaras* we can generate many more variations. The computational process leads to 12 such variations for *Vadi-Samvadi*, ‘ga’ and ‘ni’ *swaras*. For the pair ‘ga’ and ‘dha’ *swaras* as *Vadi* and *Samvadi* we get 4 such *Ragas* of the *Sampurna-Oudava* category.

Oudava- Shadava Ragas:

In the case of *Oudava-Shadava Ragas* two *swaras* are deleted from the *Aroha* and one *swara* is deleted from the *Avroha*. Here the process is shown in a step-by-step manner. First, the original seed *Raga* of *Gandhara Gana* is shown. Multiple variations are possible with the seed *Raga* itself but here just one variation is chosen to show the process. The main purpose is to explain the process and to enlist the generated variations.

Seed *Gandhara Gana Raga* = [[‘dha’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘ma’, ‘re’], [‘pa’, ‘sa’], [‘ni’], [‘ga’]] -this has seven *swaras*. Multiple *Oudava-Shadava Ragas* can be generated from this but here just one case is taken where *Anya Samvadi swara* ‘dha’ is deleted. This will lead to the following *Shadava-Shadava Raga*.

Shadava-Shadava Gandhara Gana Raga = [[[‘**rkt**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘ma’, ‘re’], [‘pa’, ‘sa’], [‘ni’], [‘ga’]], = [[[‘**rkt**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘ma’, ‘re’], [‘pa’, ‘sa’], [‘ni’], [‘ga’]]]- *Anya Samvadi swara* ‘dha’ is eliminated. This has six *swaras*. This specific instance of *Shadava-Shadava Raga* is taken as a base and variations for *Oudava-Shadava Ragas* are generated from it. Many more such variations are possible but here just one example is taken for the sake of brevity.

Variation for *Oudava-Shadava Gandhara Gana Raga* = [[[‘**rkt**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘**rkt**’, ‘re’], [‘pa’, ‘sa’], [‘ni’], [‘ga’]], [[‘**rkt**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘ma’, ‘re’], [‘pa’, ‘sa’], [‘ni’], [‘ga’]]]- *Anya Samvadi swara* ‘dha’ and primary *Anu-Anuvadi swara* ‘ma’ is eliminated from the *Aroha* while only ‘dha’ is deleted from *Avroha*.

Variation for *Oudava-Shadava Gandhara Gana Raga* = [[[‘**rkt**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘ma’, ‘**rkt**’], [‘pa’, ‘sa’], [‘ni’], [‘ga’]], [[‘**rkt**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘ma’, ‘re’], [‘pa’, ‘sa’], [‘ni’], [‘ga’]]]- *Anya Samvadi swara* ‘dha’ and secondary *Anu-Anuvadi swara* ‘re’ are eliminated from the *Aroha* while only ‘dha’ is deleted from *Avroha*.

Variation for *Oudava-Shadava Gandhara Gana Raga* = [[[‘**rkt**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’], [‘ma’, ‘re’], [‘**rkt**’, ‘sa’], [‘ni’], [‘ga’]], [[‘**rkt**’, ‘rkt’, ‘rkt’, ‘rkt’, ‘rkt’,

'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']]]- *Anya Samvadi swara* 'dha' and primary *Anuvadi swara* 'pa' is eliminated from the *Aroha* while only 'dha' is deleted from *Avroha*.

Variation for *Oudava-Shadava Gandhara Gana Raga* = [[['**rkt**', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['**rkt**'], ['ga']], [['**rkt**', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']]]- *Anya Samvadi swara* 'dha' and *Samvadi swara* 'ni' are eliminated from the *Aroha* while only 'dha' is deleted from *Avroha*.

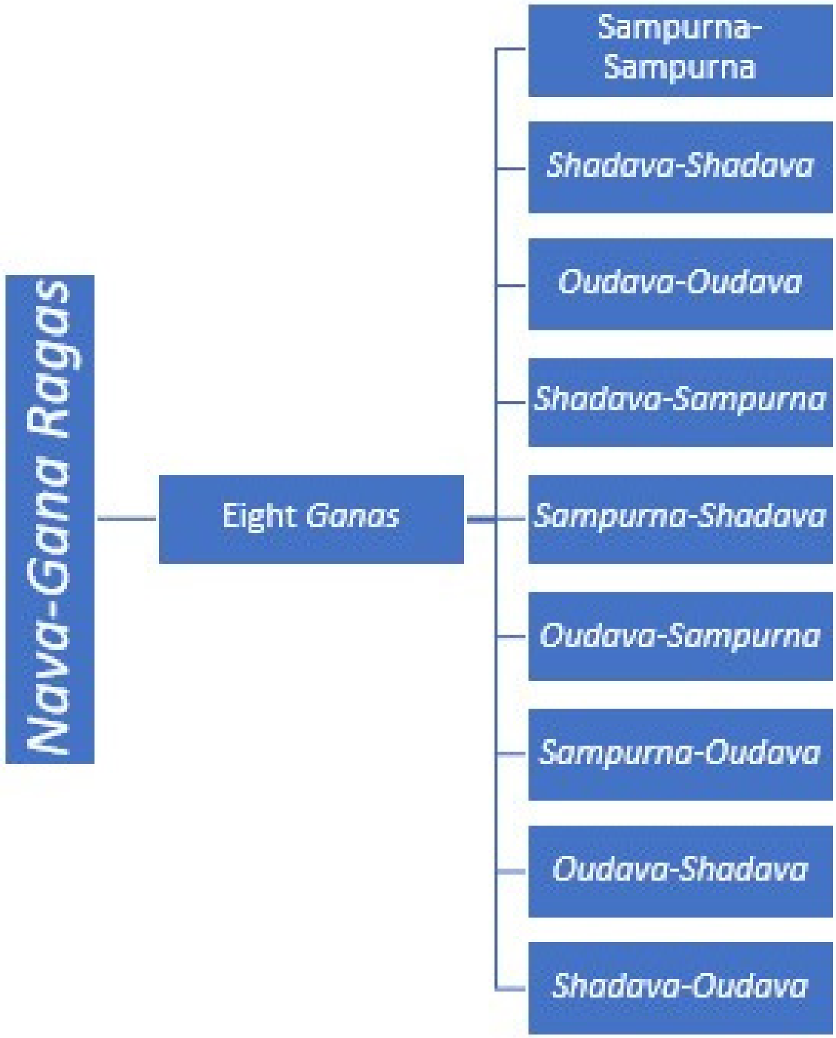
These are the few sample variations of *Oudava-Shadava Ragas*. If we change *swaras* 're', 'dha' and 'ma' to 'kre', 'kdha' and 'mat' by permutations many more variations will be generated. All these variations will be valid *Oudava-Shadava Ragas*.

Shadava-Oudava Ragas:

As discussed in the above case of generating *Oudava-Shadava Ragas*, in the same manner *Shadava-Oudava Ragas* can be generated. Taking the same above-mentioned *Shadava-Shadava Raga* of *Gandharva Gana* where *Anya Samvadi* 'dha' is eliminated, many variations for *Shadava-Oudava Ragas* can be generated. By now the overall pattern is clear and therefore, the samples for this category are not provided here.

The description of the categories of *Ragas* is complete here. *Raga* categories are important to understand the overall structure of the *Raga* system. *Ragas* belongs to *Ganas*. The *Ganas* are the broad classes where all the *Ragas* can find their place. There are nine *Ganas* as mentioned earlier. There are many *Ragas* in each *Gana*. So, it is necessary to make sub-classes or categories of *Ragas* to simplify our understanding of *Ragas*. Based on the simple logic of the number of *swaras* in the *Aroha* and *Avroha,* categorization is possible. *Natyashastra* uses this logic for the categorization of *Taanas*. Taking inspiration from there the tradition itself has started classifying *Ragas* using the above-mentioned categories. The tradition is well aware of this method of categorization. The GTIM tries to position this categorization in a proper logical manner under the *Gana* system. There are *Ganas* and within the *Ganas,* there are categories of *Ragas*. *Ragas* within every *Gana* can be thus further categorized as *Sampurna-Sampurna Ragas, Shadava-Shadava Ragas, Oudava-Oudava Ragas, Shadava-Sampurna Ragas, Sampurna-Shadava Ragas, Oudava-Sampurna Ragas, Sampurna-Oudava Ragas, Oudava-Shadava Ragas,* and finally*, Shadava-Oudava Ragas*. There exists one more category of *Ragas* where there are different *Varjya swaras* in the *Aroha* and *Avroha*. This is called the category of 'Different *Varjya swara Ragas*' in GTIM and is classified under the ninth *Gana* called *Prakirna Ragas* because of its complex nature. The 'Special-*Shadava-Shadava Ragas*' fall under the category of *Shadava-Shadava Ragas*. A Chart of *Nava-Gana Ragas* with eight *Ganas* and nine categories is as follows:

Categories (*Vargas*) of *Ragas*



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CHAPTER 16

The Compulsions of Consonances - Augmented *Ragas*

Introduction

We are discussing the *Raga* generation and classification processes in the realm of the 'Generative Theory of Indian Music' (GTIM). Initially, the theory defined and characterized the tuning systems leading to the establishment of scales. That led to the discussion on the logical foundations of Indian music followed by the laws of logic of music. The characterization of *Ragas* sets the tone of the discussion of the GTIM. Then there was a discussion on the establishment of the *Nava-Gana* system. At this point, GTIM has introduced the concept of 'Seed *Ragas*' which is a novel concept. The GTIM has introduced this concept as a logical necessity. The GTIM attempts to articulate the foundational logic behind the generation of *Ragas*- it includes all the existing *Ragas* as well as all the possible *Ragas*. So, the entire ongoing discussion has this particular context.

It is becoming clear by now that the process of transformation of a seed *Ragas* into the real *Ragas* has multiple facets. The seed *Ragas* are variations on the original *Gana Raga*. Seed *Ragas* are hypothetical or potential *Ragas*. They become real *Ragas* if they fulfil the criteria of musical logic. As a part of the process, we may eliminate one or two *swaras* from the seed *Raga* and we generate *Shadava* or *Oudava Ragas*, based on musical logic, as discussed in the previous chapter. Similarly, there are cases of seed *Ragas* where one or two *swaras* need to be added to them to transform them into real *Ragas*. Otherwise, these seed *Ragas* do not qualify as real *Ragas*. This chapter is thus dedicated to discussing the process of adding the required *swaras* to seed *Ragas*.

As mentioned above, there are one or two *Varjya swaras* in a *Raga*, similarly, there are one or two or at times more than two *swaras* added to the basic set of *swaras* of a *Raga*. Such *Ragas* are called 'Augmented *Ragas*' in the GTIM. These additional *swaras* are the dual *swara* forms of some of the basic *swaras* of a *Raga*. *Ragas* have seven *swaras* in *Aroha* and *Avroha* each and so are called '*Sampurna Ragas'*. *Ragas* with six *swaras* in *Aroha* and *Avroha* each are called

'*Shadava Ragas'* and *Ragas* with five *swaras* in *Aroha* and *Avroha* each are called *Oudava Ragas*. We assume that most of the *Ragas* have such a simple structure. But that is not the case. Contrary to this general assumption, most of the *Ragas* do not have such a simple structure. They have one or two additional *swaras* either in *Aroha* or *Avroha* or in both. A general norm in such a case is that, if a '*Shuddha*' or '*Teevra*' *swara* is there as an additional *swara* in a *Raga* then it is made part of the *Aroha* and if the additional *swara* is a flat or *Komal swara* then it is used in the *Avroha*. However, there are many exceptions to this general norm based on the aural laws. When *swaras* are added to the seed *Raga* it is called the process of augmentation. A natural question will arise in the mind what is the requirement of such an augmentation? Augmentation is needed because if these *swaras* are not added to the seed *Raga* then such a seed *Raga* will sound incomplete from the aural logical point of view. It's a natural aural reasoning process that is operational when we listen to music. Sometimes we intuitively feel that something is missing there. This feeling is intuitive but it has roots in the aural reasoning process. The common audience is not aware of the logic though, they are aware of the experience.

Augmented *Ragas*

The GTIM attempts to articulate these intuitive processes logically. Especially, the law of co-existence of *swaras* as discussed under the laws of musical logic- LML, plays a very important role in the process of augmentation. If in the *Raga* there is a given set of *swaras* but somehow, the absence of certain consonant *swaras* is felt and the musicians as well as the audience feel the lacuna then the appropriate consonant *swaras* are added. For instance, if there exists *swara* Ni in a *Raga*, and if '*Teevra'* Mat is not there in the basic set of *swaras* of the *Raga* then the absence of *Teevra* Mat is felt strongly. This is a well-established phenomenon. While rendering *Aalaps* of such a *Raga* the performer will be tempted to use the *Teevra* Mat *swara* in some way or other. It happens because by the aural law of the co-existence of *swaras* Mat and Ni *swaras* demand each other's existence. In the GTIM, for the computational generation of augmented *Ragas*, a procedure is developed. When initially, simple *Sampurna-Sampurna Ragas, Shadava-Shadava Ragas* or *Oudava-Oudava Ragas* are generated, they are considered as original seed *Ragas* as a part of the generative process. Then it is checked whether there are *swaras* that demand the existence of their respective co-*swaras* in the *Ragas*. If such co-*swaras* do not exist in the *Raga* then the laws of co-existence of *swaras* are applied and the respective co-*swaras* are added to the *Ragas* and such *Ragas* are separated from the original seed *Ragas*. These *Ragas* become the new forms of the seed *Ragas* called 'Augmented *Ragas*'. Sometimes there is a demand for just one additional *swara,* or sometimes there is a need for two additional *swaras* in the *Raga*. Most prominent cases of 'Augmented *Ragas*' are where the dual form of Ma/ Mat is required or a dual form of Ni/ Kni is required or there is a need for dual forms of both the *swaras* Ma/ Mat and Ni/ KNi. The majority of 'Augmented *Ragas*' have such a requirement. This is the first category. There is another category where there is a need for dual *swaras* forms of the *swaras* such as Re/ KRe, Ga/ KGa, and Dha/ KDha *swaras*. This is the second category. In this category, at times there is a need for one, two or even three additional *swaras* in a *Raga*. There is a third category where any permutation and combination of the above-mentioned possibilities is necessary. At times such *Ragas* have even five additional *swaras* in the *Raga*. It means that except *swaras* Sa and Pa, all the other *swaras* have dual forms, either *Komal* or *Teevra* and all such *swaras* can have dual forms in the *Raga* based on the laws of co-existence of *swaras*.

It is insightful to study the phenomenon of augmentation. Some *Ragas* whether *Sampurna-Sampurna, Shadava-Shadava* or *Oudava-Oudava Ragas* do not need such an augmentation. For instance, *Raga Bhupa* has Sa, Re, Ga, Pa, Dha as a basic set of *swaras*. The pairs Sa-Pa, Re-Pa, and Ga-Dha are self-sufficient in themselves from the point of view of the law of co-existence of *swaras*. So, in the *Raga Bhupa,* there is no need for augmentation. Similarly, in the *Raga Bhairavi* for that matter, there is no need for augmentation. It has basic *swaras* as Sa, KRe, KGa, Ma, Pa, KDha, KNi. In *Bhairavi* the pairs, Sa-Pa, Sa-Ma, KRe-KDha, KGa-KNi, and Ma-KNi are in adherence with the law of co-existence of *swaras* and so there is no need for augmentation. These are straightforward examples of *Ragas* where there is no need for augmentation. But many a time because of the peculiar nature of the *Vadi-Samvadi* pairing in the *Raga*, augmentation becomes inevitable and complicated. For instance, *Raga Khamaj* has Ga-Ni *Vadi-Samvadi* pair with the *swaras* Sa, Re (*Arohi Varjya*), Ga, Ma, Pa, Dha, Ni and KNi. Here we can see pairs of Sa-Pa, Re-Pa, Re-Dha, and Ga-Ni. As per the law of co-existence of *swaras*, if there is a Ma in the *Raga* then it will demand the presence of KNi. Since Ga is *Vadi swara* its *Samvadi swara* Ni has to be there. Ma has some support from Sa *swara* but Sa is omnipresent that support is not enough. Ma is also the primary *Anu-Anuvadi* for Ga and so it is an important *swara* and Ma is used frequently in the *Raga Khamaj* rendering. Therefore, Ma *swara* demands the presence of KNi *swara* in the *Raga*. As per the norm, thus KNi is used in the *Avroha* while rendering the *Raga*. Many such examples can be cited for the necessity of the augmentation of *Ragas*.

There is one more category of augmented *Ragas* which is called *Tri-Gandhara Ragas*. This category is classified under '*Prakirna*' *Ragas* in the GTIM. Under this category of *Ragas*, instead of dual forms of *swaras,* there are triple forms of Ga and Ni *swaras*. Due to this unusual character of these *Ragas*, they are classified under *Prakirna Gana*/ class. A well-known example of this category is *Raga Lagan Gandhar*. In this *Raga,* three forms of *Gandhara*- Ga, KGa and BGa (*Ati-Komal Gandhara* which is also called Bharata Muni's *Gandhara*) are used and as follows there are three forms of *Nishad*- Ni, KNi, and BNi or Bharat Muni's *Gandhara*. In this *Raga* since there are three forms of *Gandhara,* by the law of co-existence of *swaras* even the three forms of *Nishad* are needed. So, there is a pairing of Ga-Ni, KGa-KNi and BGa-BNi as per the law of co-existence of *swaras*.

Dual *Swara*-form *Ragas*

There is an interesting fallout of the process of augmentation. As explained above, certain *swaras* necessitate the presence of certain specific *swaras* in the *Raga* and therefore, *swaras* are added to the *Raga*. Often it so happens that the counterpart *swara*-forms of these added *swaras* are already present in the *Raga*. Many *Ragas* in Indian music have two forms of the same *swara*. For example, the *Raga Khamaj* has *swara* 'ni' in *Aroha* but in the *Avroha* there is 'kni' instead of 'ni'. Now in all such cases 'ni' and 'kni' are not treated as different *swaras*. They are considered as the two forms of the same *swara* and are treated as the same *swara*. They are also called dual forms of the *swara* in GTIM.

We can understand the process of augmentation through a hypothetical example as follows. As already discussed, a *Raga* is represented as follows.

Raga= [[*Anya swara* (secondary *Samvadi*), dual *Madhyama* if any, dual *Nishad* if any, dual *Rishabha* if any, dual *Gandhara* if any, dual *Dhaivata* if any, Triple *Gandhara* if any (Bharata Muni' *Gandhara*), triple *Nishad* if any (Bharata Muni's *Nishada*)], [primary *Anu-Anuvadi*, secondary *Anu-Anuvadi*], [primary *Anuvadi*, secondary *Anuvadi*], [Primary *Samvadi*], [*Vadi*]].

The hypothetical example of *Gandhara Gana Raga* that we are discussing will look as follows after adding the dual forms of swaras.

The basic or seed *Gandhara Gana Raga* is as follows.

R = [['dha', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt', 'rkt'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']].

If we add all possible representations of *swara*-forms, then it will look as follows.

R = [['dha', 'mat', 'kni', 'kre', 'kga', 'kdha', 'bga', 'bni'], ['ma', 're'], ['pa', 'sa'], ['ni'], ['ga']].

This is a hypothetical example where the fist list is fully occupied by *swaras*. There is no 'rkt' *swara* in this list. The first place is the secondary *Samvadi* i. e. 'dha'. The next two places are for *swara*-forms of 'ma' and 'ni' *swaras* respectively. Here we can see the 'mat' is the *swara*-form of 'ma'. It means this hypothetical *Raga* has two forms of *swara* 'ma'. Now as per the tradition if there are two forms of a *swara* in a *Raga* then the *Teevra*/ *Shuddha* form should be used in the *Aroha* while the *Komal* form of the *swara* is supposed to be used in the *Avaroha*. So accordingly, the *Aroha* and *Avroha* respectively of this hypothetical *Raga* will look as follows.

Aroha = [['dha', ''rkt', 'rkt', 're', 'ga', 'kdha', 'rkt', 'rkt',], ['mat', 're'], ['pa', 'sa'], ['ni'], ['ga']].

Avroha = [['kdha', 'rkt', 'rkt', 'rkt', 'kga', 'rkt', 'bga', 'bni'], ['ma', 'kre'], ['pa', 'sa'], ['kni'], ['ga']].

Of course, this is a completely hypothetical example. Such a Raga does not exist. This *Raga* uses all the 12 *swaras* and additional Bharat Muni’s *Gandhara* and *Nishada swaras* also. So, such a *Raga* is impossible to render. This structure is presented here to illustrate how the dual forms of *swaras* are depicted in the *Raga* structure.

This is the standard way to represent the dual-form *swaras*. However, there are many ancillary rules those are applied in special cases. For example, if a *Vadi swara* is ‘ma’ and there is a ‘mat’ *swara* as an additional *swara* form then both the *swara* forms are used in *Aroha* as well as in *Avaroha*. There is another rule of thumb and accordingly if ‘mat’ is a part of the main *Raga* and ‘ma’ is an additional *swara*-form then ‘mat’ should be used in *Aroha* as well as in the *Avroha* while ‘ma’ should be used only in *Avaroha*. A typical example is *Raga Maru Bihaga* in this case.

It is very interesting to know that computational analysis shows that most of the *Ragas* have *swara*-forms of ‘ma’ and ‘ni’ *swaras*. The theoretical and logical explanation for this phenomenon is very insightful. *Ragas* have seven, six, or five *swaras* in *Aroha/Avaroha*. However, there exists an aural logical dynamic between and among *swaras*. As we already know that ‘sa’, ‘pa’, and ‘ma’ are considered ‘*Nitya*’ *swaras*. This is because due to their natural harmonic strength, they are very strong and musically stable. The *swara* ‘sa’ being a tonic is the anchoring force for a *Raga*. The *swara* ‘pa’ and ‘ma’ are the natural supporting *swaras* due to the *Shadja-Panchama Bhava* principle. They are natural *Samvadi swaras*. So, the position of ‘sa’ is very strong as an anchor because ‘pa’ and ‘ma’ both support it harmonically. But the same is not the case with ‘pa’ or ‘ma’. If there is a *swara* ‘re’ in the *Raga* then ‘pa’ also gets the harmonic support from the anchor ‘sa’ and *swara* ‘re’. But without ‘re’ the *swara* ‘pa’ is less strong as compared to ‘sa’. Similarly, in the case of *swara* ‘ma’ the presence of *swara* ‘kni’ (*Komal Nishad*) is important because there exists *Shadja-Madhyama Bhava* between ‘ma’ and ‘kni’. But instead of ‘kni’ if a *Raga* has ‘ni’ *swara* then *swara* ‘ma’ becomes less strong as compared to ‘sa’ and ‘pa’. Then how to compensate for this lacuna? This necessitates the presence of ‘kni’ *swara* in the *Raga*. So ‘kni’ is added as an additional *swara* form in the list of *swaras*. In the *Raga* representation scheme, there is a dedicated place or location in the list of *Anya swaras*. So as a general rule of thumb, if a *Raga* has ‘ma’ as a *swara* member and there is a *swara* ‘ni’ as a member of a *Raga* then in such a case ‘kni’ is added as an additional *swara* to the *Raga*. In this regard certain pairs of *swaras* are important. These are derived from the law of co-existence of *swaras*. The pairs: < ‘sa’, ‘pa’>, <‘sa’, ‘ma’>, <pa’, ‘re’>, <‘ma’, ‘kni’>, <‘kre’, ‘mat’>, <‘mat’, ‘ni’>, <ga’, ‘ni’>, <‘kga’, ‘kni’> are important. Each member of the pair necessitates the presence of the other member of the pair. So, if there is a *swara* ‘mat’ in the *Raga* then ‘ni’ is necessary in the *Raga*. If it is not there then it is added to the *Raga*. Similarly, if there is a ‘kre’ *swara* then it will necessitate the presence of ‘mat’ in a *Raga*. With this logic, the additional *swara* forms are added to the *Raga* description. The most frequently occurring *swara* forms are ‘mat’ and ‘kni’ in *Ragas*. Because most of the *Ragas* have ‘ma’ and ‘ni’ as important *swara* members of the *Raga*. *Vadi, Samvadi, Anuvadi* and *Anu-Anuvadi* are the important *swaras*. If the members of the above-mentioned pairs are one of these *swaras* then they will necessitate the presence of the other members as explained earlier. *swara*-forms of ‘re’, ‘ga’, and ‘dha’ occur less frequently.

Normally, there can be one or two dual *swara*-forms prevalent in a *Raga*. However, there are *Ragas* where there can be more than two *swara*-forms. If a *Raga* has up to two *swara* forms such as ‘mat’ and ‘kni’ or ‘ma’ and ‘ni’ and so on then such *Ragas* are considered regular *Ragas*. But if there are more than two *swara* forms in a *Raga* then such *Ragas* are categorized separately and called ‘Multi-Dual *Swara Ragas’*. There are many such *Ragas*.

Order of ‘Dual *Swara*’ Generation

In the computational procedure, the dual forms of *swaras* are generated based on the law of co-existence of *swaras*. When initially seed *Ragas* are generated, all the seed *Ragas* are supposed to be hypothetical *Ragas* or possible *Ragas*. They are not real *Ragas*. Some of them are entitled to become full-fledged *Ragas* because all important *swaras* like *Vadi* and others have their supporting co-existing *swaras* present. For instance, *Raga Bhairavi* is a complete *Raga* at the stage of seed *Raga* itself. It has *swaras* such as Sa, KRe, KGa, Ma, Pa, KDha, KNi and higher Sa. *Vadi* is Pa and *Samvadi* is Sa. KGa is the primary *Anuvadi* and Ma is the primary *Anu-Anuvadi*. It is interesting to see that all these important *swaras* have their co-existing pair of *swaras* as members of the *Raga*. Pa has its co-existing *swara* Sa. The same is the case with Sa because Pa is there and even Ma is also there. KGa has its supporting *swaras* like KNi and KDha in the basic set of *swaras* of this *Raga*. Ma has the support of Sa and KNi. Even the *Anya swara* KRe has the support of KDha as its co-*swara*. So, all the *swaras* of *Raga Bharavi* are well-supported from within. Therefore, at the stage of seed *Raga* itself, *Bhairavi* is a complete *Raga*. But this is not the case with all the seed *Ragas*. When important *swaras* in the *Raga* do not have harmonic support from their co-*swaras*, then the required co-*swaras* need to be added to the basic set of a seed *Raga*. Sa and Pa do not have dual forms but rest of the *swaras* have dual forms as Re-KRe, Ga-KGa, Ma-Mat, Dha-KDha, and Ni-KNi. In a seed *Raga* by default at least one form of these five *swaras* has to be there otherwise the seed *Raga* is not complete. When the co-*swaras* are added they are bound to be the *swara*-forms of the existing member *swara* of the seed *Raga*. Therefore, all such dual *swaras* are called dual *swara* forms because their counter parts are already there in the seed *Raga*. As we know when there is a requirement of a co-*swara* for a particular *swara* that has to be added. Mat and Ni are the *swaras* which are the most preferred *swaras* as dual *swaras*. The original seed *Ragas* always have Ma or Mat as a member and Ni or KNi as a member. Now the seed *Raga* having Ma and Ni as members, Ma demands the presence of KNi as a co-*swara* and in the *Raga* KNi becomes the dual form because Ni is already there. Similarly, if the seed *Raga* has Mat as a member and KNi is already there in the *Raga* then Mat will necessitate the presence of Ni and becomes the dual form of KNi. Therefore, Ma/ Mat and KNi/ Ni are the most preferred dual forms of *swaras*. As a part of the augmentation process of *Ragas*, therefore, first these *swaras* are added to the basic set of *swaras* in the list of *Anya swaras*.

One very important factor needs to be kept in the mind that we are adding dual forms of *swaras* to the seed *Ragas*. It means that the original form of the *swara* has to be there in the *Raga*. This is very important. The above discussion is completely valid in the case of seed *Ragas* that are *Sampurna Ragas*. But in the case where seed *Ragas* are *Shadava* or *Oudava* then the required *swara* form is added if and only if its counterpart *swara*-form is present in the seed *Raga* as a member. For example, if there is a Mat in the *Shadava* seed *Raga* so it will seek the presence of Ni, but if KNi is not there then we cannot add Ni as a Dual *swara*. Then the next co-*swara* of Mat is KRe. If it is already there in the *Raga* then there is no question of dual *swara* form but if re is there then KRe needs to be added as a dual *swara* in the *Raga.*

In terms of emotive strength, Mat is very strong emotionally. So whenever, Mat is there in the *Raga*, it will also seek the presence of Ni and KRe. So, a seed *Raga* may have Ni and KRe as co-*swaras* of Mat.

Second in order of preference of dual *swaras* is the *swara* KRe. Similarly, whenever the seed *Raga* has KRe as a member, it will seek the presence of Mat. This is a peculiar case. KRe is an emotive *swara* and it has two co-*swaras* as KDha and Mat. If Mat is there then KRe's requirement is fulfilled. But if Mat is not there then KDha will need to be added in the Raga.

The next important pair of *swara* is KGa and KNi. *Raga Jayajayavanti* has both the forms of Ga and Ni. Whenever there is a KGa in the *Raga* it will need the support of KNi also. So dual *swara* form of Ga is dependent on the existence of KNi *swara* in the *Raga*. This is not a very strong association as compared to Mat-Ni or Mat-Kre associations. Therefore, this association is not absolutely mandatory, however, they co-exist most of the times if the other stronger pairs discussed above are not there in the *Raga*. KGa-KNi association adds a beauty to the *Raga* in a very delicate way.

A valuable insight emerging from this discussion is that in most of these cases, emotive *swaras* or chromatic notes are at the heart of these relationships. The other *swara* relationships involving *Shuddha swaras* are not so strong that they mandatorily necessitate the presence of other co-*swara*. The pairs such as Ga-Ni, and Re-Dha, are important but belong to the third order in the hierarchy of preferences. This whole discussion is from the point of view of generating dual forms of *swaras* in a seed *Raga*. So, in the hierarchy of the generative process the order of preferences would be as follows-

First order- Mat and/ or KNi, Ma and /or Ni

Second order- KRe, KGa, KDha

Third order- Re, Ga, Dha

Sa and Pa do not have the dual *swara* forms. This order is important because while generating *Ragas* from the seed *Ragas*, it may be possible to generate *Ragas* by multiple methods or ways. This order of generating dual *swara* is an effort to streamline the computational process. The description of the augmentation process is complete here.

Eliminating Competing *Ragas*

In the computational process of *Raga* generation, a huge number of *Ragas* get generated by applying the aural laws and other musical- aural norms. In such a generation there will be three to six *Ragas* having the same set of *swaras*. If we cross-check with the available data of existing *Ragas*, we realize that for the same set of *swaras,* so many *Ragas* do not exist. There can be two or at most three *Ragas* with such a unique set of *swaras*. It means that there are extra *Ragas* generated through the computational process. Since they are generated by following computational process and the aural logic, they are considered valid *Ragas*. It may be argued that they can be treated as new *Ragas*. But for that we need to develop a scheme of criteria of deciding which are the new *Ragas*, which are the redundant *Ragas* and which are the valid *Ragas*. After a thorough analysis of existing *Ragas*, it was realized that in such a situation some *Ragas* are redundant. This can be illustrated by an example. Take the case of five *swara Ragas* such as *Bhupa* and *Deshakar Ragas*. Both the *Ragas* have same set of *swaras*- Sa, Re, Ga, Pa, Dha and higher Sa. With this set of *swaras* following pairs of *Vadi-Samvadi* are possible. Sa-Pa, Re-Pa, Re-Dha, Ga-Dha, Pa-Sa, Pa-Re, Dha-Ga, Dha-Re. It means that there can be eight *Ragas* possible if we follow a permutation process of *Raga* generation. However, our data of existing *Ragas* show us that there are only three *Ragas* that are in existence and survived the test of time. They are *Bhupa* with Ga-Dha *Vadi-Samvadi* pair, *Deshakar* with Dha- Ga *Vadi Samvadi* pair and *Raga Jait Kalyan* with Pa-Sa *Vadi-Samvadi* pair. Many text books on music also mention *Raga Pahadi* with Sa-Pa *Vadi-Samvadi* pair belonging to this category however, in actual practice *Pahadi Raga* uses extra swaras like, Ma, Ni and Mat while rendering the *Raga*. So, it is not considered here as belonging to this category. So why only above-mentioned three *Ragas* are in existence? *Raga Bhupa* is the most popular *Raga* out of these three and the *Raga Deshakar* is the second in line. *Jait Kalyan* is not very popular and heard very rarely but it is documented and considered as a good *Raga*. It means that out of eight possible *Ragas* only three *Ragas* are in existence.

Let us treat all these eight *Ragas* as competing *Ragas*. The analysis will help in developing insights. With the Sa-Pa *Vadi-Samvadi* pair, one *Raga* is possible and we know that it is known as *Pahadi*. *Vadi* Sa is a tonic *swara* and as we know that it is an omnipresent *swara* due to *Tanapura's* harmonic ambience. The omnipresence of Sa makes it banal and weak. So probably *Pahadi Raga* could not survive in its pentatonic form. It may be the case that in earlier days when *Tanapura* was not in vogue, the *swara* Sa had its strong harmonic status and *Raga Pahadi* came into practice. But as *Tanapura* became popular all the *Ragas* with Sa as *Vadi swara* started perishing. But this is just a guess. We do not have any historical proof. If we take the case of Re as a *Vadi swara* then there are two possibilities- Re-Dha *Vadi-Samvadi* and Re-Pa *Vadi-Samvadi Ragas*. But in reality, none of them exists. The reason is that when Re is a *Vadi* it has two *Anu-Anuvadis*- Sa and Ga. Sa is omnipresent and therefore weak but Ga is harmonically very strong than Re in every respect. Ga is neither *Ardha-Varjya* nor has a dual form. So, Ga cannot become weak in any sense and it will always dominate the *swara* Re. That is the reason *Ragas* with Re as *Vadi* could not survive with this *swara* set. This is the justification of the logic of music. As discussed earlier in the chapter on the laws of musical logic, all the aural laws play a very decisive role in such a situation. GTIM provides a valid justification for all such cases that are being discussed right now. Ga as a *Vadi* is very strong and therefore, we have a very popular *Raga* called *Bhupa*. It adheres to the laws of musical logic. With Pa as a *Vadi swara,* there are two possibilities for *Ragas*. One with Pa-Sa *Vadi-Samvadi* pair and the other with Pa-Re *Vadi-Samvadi* pair. Here there is a very interesting competition between Sa and Re *swaras* as *Samvadis*. When *Nitya swara* is competing with other *swaras* the *Nitya swara* wins and so here Pa-Sa *Vadi-Samvadi* pair wins and we have *Jait Kalyan Raga*. Re naturally becomes the *Anya Samvadi*. However, like Sa, Pa is also in abundance in the *Tanapura* harmonic ambience and therefore Pa as a *Vadi* cannot assert itself. At the same time, its *Anuvadi* Ga is very strong and therefore, while rendering a *Raga Jait Kalyan* one has to guard against the impact of Ga in rendering. *Swara* phrases with Ga should be used cautiously. That is the reason why *Jait Kalyan* is not so popular *Raga*. In the case of Dha as a *Vadi swara* again there are two possibilities- of having Dha-Ga and Dha-Re *Vadi-Samvadi* as competing pairs for the *Ragas*. But we know that again Ga is harmonically very strong as compared to Re as a *Samvadi* and so Ga wins over Re and the *Raga* with Re as a *Samvadi* does not survive. So, we have a *Raga Deshakar* with *Vadi* Dha and *Samvadi* Ga. But as we know usage of Ga should be minimized in rendering in the *Deshakar Raga* since it is harmonically stronger than the *Vadi* Dha. This puts limitations on *Raga Deshakar* and that is the reason it is not as popular as *Raga Bhupa*.

In the above discussion, many technical norms of aural musical logic are mentioned. The following paragraph gives some details of these norms. When *Ragas* are competing with each other they compete based on having the same set of *swaras* as discussed in the above examples. But apart from that they also compete in terms of harmonic strength of *Vadi swaras*. In the same way, there exists a competition between the primary *Anuvadis* of one *Raga* with the *Vadi* of the competing *Ragas* and a competition between the primary *Anu-Anuvadis* of one *Raga* with the *Vadi* of the competing *Ragas*. This peculiar phenomenon happens because such competing *Ragas* share the same set of *swaras*. A scrutiny of the above example suggests that as a result in most such cases, a *Vadi swara* of the *Raga* X is competing with its own *Anuvadi* or its own *Anu-Anuvadi* then such a tricky situation arises. This is because, for a *Raga* X, other competing *Ragas* have *Raga* X's *Anuvadi* or *Anu-Anuvadi* as their *Vadi swaras*. The *Raga* generation process that is discussed earlier takes care of such a competition and does the selection of valid *Ragas*. In this context, the general norms for all such cases where *Vadi* is competing with its own *Anuvadi* or *Anu-Anuvadi* are given below. The base line principle in these norms is that the *Vadi* should be harmonically stronger than its primary *Anuvadi* and primary *Anu-Anuvadi*. Secondly, if a *Vadi swara* is not strong then the primary *Anuvadi* and/ or primary *Anu-Anuvadi* should be weak due to some other conditions. Following norms provide these conditions.

- The norm is that if primary *Anuvadi* or the primary *Anu-Anuvadi* is *Ardha-Varjya* in the *Raga* and so they become weak than the *Vadi swara* then such a *Raga* is valid.
- The norm is that if primary *Anuvadi* or the primary *Anu-Anuvadi* has its one of the *Samvadis* as *Varjya* or *Ardha-Varjya* in the *Raga* and so they become weak than the *Vadi swara* then such a *Raga* is valid.
- The norm is that if primary *Anuvadi* or the primary *Anu-Anuvadi* has its *swara*-form in the *Raga* and they become weak than the *Vadi swara* then such a *Raga* is valid.
- The norm is that if primary *Anuvadi* or the primary *Anu-Anuvadi* has its both the *Anu-Anuvadis* as *Varjya* swaras in the *Raga* then such a *Raga* is selected.

Specific situations are as follows.

Vadi is competing with its own *Anuvadi*:

Normally primary *Anuvadi* is stronger than secondary *Anuvadi* in any *Raga*. Therefore, in the following cases, only the status of a primary *Anuvadi swara* is checked and compared with the harmonic status of the *Vadi swara* of the *Raga*. There are special cases when the *Vadi* of the *Raga* in question is Ma or Pa and their primary *Anuvadis* are Re or Ga respectively. In such a situation following conditions need to be fulfilled.

These are special cases.

- *Raga* is valid if- Re or Ga are *Ardha-Varjya swaras*. The norm is that if primary *Anuvadi* or the primary *Anu-Anuvadi* is *Ardha-Varjya* in the *Raga* then then they become weak as compared to *Vadi swara* and such a *Raga* is selected.
- *Raga* is selected if- Re or Ga has their one of the *Samvadis Varjya* or *Ardha-Varjya* in the *Raga*- so that Re or Ga becomes weak.
- *Raga* is selected if- Re or Ga has their *swara*-forms in the *Raga*. The norm

is that if primary *Anuvadi* or the primary *Anu-Anuvadi* has its *swara*-form in the *Raga* then such a *Raga* is selected.

- *Raga* is selected if- both the *Anu-Anuvadis* of Re or Ga are *Varjya* in the Raga. The norm is that if primary *Anuvadi* or the primary *Anu-Anuvadi* has its both the *Anu-Anuvadis* are *Varjya* in the *Raga* then such a *Raga* is selected.

If above conditions are not met with then it means that
Re or Ga is strong and so such a *Raga* with either Ma or Pa as a *Vadi swara*
is not selected.

Vadi is competing with its own *Anu-Anuvadi*:

The second case is interesting where the *Raga* has a *Vadi swara* that is competing with its own *Anu-Anuvadi swaras*. Normally, the primary *Anu-Anuvadis* of the *Ragas* is *Nitya swaras* (Sa, PA, or Ma). *Nitya swaras* are very strong due to their harmonic strength. But due to their omnipresence in the *Tanapura* ambience, their presence is taken for granted and they do not compete with the *Vadi swara*. So, the real competition arises between the *Vadi* and the secondary *Anu-Anuvadi swara*. Following norms help in selecting the *Ragas* with appropriate secondary *Anu- Anuvadi swara* in such a case.

- If both the *Anu-Anuvadis* of the *Raga* are weaker than the *Vadi swara* of the *Raga* then such a *Raga* is selected- this normally happens if *Vadi* is a *Nitya swara*.
- If primary *Anu-Anuvadi* is stronger and secondary *Anu-Anuvadi* is weaker than *Vadi* then such a *Raga* is selected.
- If secondary *Anu-Anuvadi* is a member of *Nitya swaras* then the *Raga* is selected.
- If secondary *Anu-Anuvadi* is stronger than *Vadi*- then it should be *Ardha-Varjya* then the *Raga* is selected.
- If secondary *Anu-Anuvadi* is stronger than *Vadi*- then its dual *swara*- form should be there in *Raga* then the *Raga* is selected.
- If secondary *Anu- vadi* is stronger than *Vadi*- then its both the *Anuvadis* should not be there in the original structure of the *Raga* then the *Raga* is selected.
- If secondary *Anu- Anuvadi* is stronger than *Vadi*- then such a *Raga* is eliminated.

The general norms are already mentioned and few special cases are also mentioned in the above description. There are few more generic norms that need to apply in specific cases. These are as follows.

- If *Vadi* is Sa, then *Raga* is selected by default.

- If Re, Ga, KDha or Dha are *Vadi swaras* and *Nitya swaras* are primary *Anuvadi* then *Ragas* are selected by default.
- If primary *Anuvadi* is Sa then the *Raga* is selected because Sa is *Nitya Anuvadi*.
- If primary *Anuvadi* is stronger than *Vadi*- then it should be *Ardha-Varjya* then only the *Raga* is selected.
- If primary *Anuvadi* is stronger than *Vadi*- then its dual *swara*-form should be there in *Raga* then only the *Raga* is selected.
- If primary *Anuvadi* is stronger than *Vadi*- then its both the *Anu-Anuvadis* should not be there in the original *Raga* then only the *Raga* is selected.
- Apart from the above conditions if primary *Anuvadi* is stronger than *Vadi*- then such a *Raga* is not selected.

The phenomenon of eliminating competing *Ragas* having same set of *swaras* is quite complicated. The above-mentioned norms have been developed after thorough testing of the available data of existing *Ragas*. This indicates the importance and active role played by the laws of musical logic- especially the role of the law of harmonic strength of *swaras* and the law of the co-existence of *swaras* is very critical.

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CHAPTER 17

The *Prakirna Ragas*

Introduction

There are certain *Ragas* that are unique in terms of the number of *swaras*, the number of *Varjya swaras*, patterns of *Aroha* and *Avroha*, or the number of dual *swaras*. Most of the *Ragas* that are commonly practised are classified under eight *Ganas*. These *Ganas* are namely, *Panchama Gana, Madhyama Gana, Gandhara Gana, Rishabha Gana, Komal Gandhara Gana, Komal Rishabha Gana, Dhaivata Gana* and *Komal Dhaivata Gana*. This scheme of eight *Ganas* is competent to classify all the regular *Ragas*. But there is a significant chunk of *Ragas* which need to be classified separately. All such *Ragas* are classified under the class or *Gana* called *Prakirna Gana*. The peculiar feature of this *Gana* is that the *Vadi swara* of most of the *Ragas* in this *Gana* is *Shadja swara* by default and in certain cases, *Panchama* and *Madhyama* occupy the place of *Vadi swara*. This needs some justification. *Ragas* covered under this *Gana* are unique *Ragas* in some musical sense. Types of *Ragas* that fall under this *Gana* are *Tri-Gandhar Ragas, Different Varjya swara Ragas, Chatuswari Ragas*, and complex *Ragas* where more than two dual *swara* forms are used. For all these types of *Ragas*, *Shadja* is considered the default *Vadi swara*. Other so-called deserving *Vadi swaras* in these *Ragas* do not qualify as *Vadi swara* because they are somehow harmonically weak. Specifically, the original *Vadi swaras* of these *Ragas* are weak due to inherent complexities or due to some other reasons. In such cases, the *Vadi swara* either has dual *swara*-forms in the *Raga* or their co-*swaras* are *Varjya* in the *Raga* or they are harmonically weak by themselves. Therefore, Sa being the tonic *swara* becomes the natural choice as a *Vadi swara*. But in this case, also due to the prevalence of *Tanapura* harmonics the *swara* Sa becomes omnipresent and mundane. To compensate for this lacuna either Pa or Ma, (whichever is stronger) plays the role of the *Vadi swara* in some of these *Ragas*. Apart from that the deserving *Vadi swaras* or traditionally accepted *Vadi swaras* are important and deserve to be the *Vadi swaras* if they escape the above-mentioned conditions and are harmonically strong enough. This perspective is important because *Prakirna Ragas* are special *Ragas*. Therefore, for *Prakirna Ragas* the *swara* Sa is assumed as the default *Vadi swara* but wherever possible, Pa or Ma are considered *Vadi swaras*. Traditionally acceptable other *Vadi swaras* are also preserved wherever possible. A brief discussion of *Prakirna Gana Ragas* with examples will be appropriate here.

Different *Varjya Swara Ragas*

So far, we have discussed types of *Ragas* that have one or two *Varjya swaras* in *Aroha/ Avroha* resulting in various categories. Out of these, categories such as *Oudava-Sampurna, Sampurna-Oudava, Shadava-Sampurna, and Sampurna-Shadava* have one or two *swaras* omitted only from the *Aroha* or from the *Avroha*. In the case of categories such as *Shadava-Shadava, Oudava-Oudava, Oudava-Shadava* and *Shadava-Oudava Ragas*, normally particular *swara* is omitted from the *Aroha* and the same *swara* is omitted from the *Avroha*. Similarly, if two *swaras* are deleted from the *Aroha* then the same two *swaras* are deleted from the *Avroha*. However, there are many *Ragas* where specific *swara/s* are omitted in the *Aroha* but in the *Avroha*, the same *swara/s* are not omitted. On the other hand, different *swara/s* are made *Varjya*. Such *Ragas* are termed as 'Different *Varjya Swara*' *Ragas* in the GTIM. There are many such *Ragas* where *Aroha* and *Avroha* have different *Varjya swaras*. For instance, *Raga Gavati* has *swara* 're' and 'dha' *Varjya* in *Aroha* while *swara* 'kni' i. e., *Komal Nishad* is *Varjya* in *Avroha*. Both the above-mentioned *Ragas* are quite popular. Following are some good examples of such *Ragas*.

Different *Varjya Shadava-Shadava Ragas:*

Raga Bahar: A very popular *Raga Bahar* has, as per one convention, *swara* 'Re' and 'Pa' are *Varjya swaras* in the *Aroha* while in the *Avroha, swara* 'dha' is *Varjya*. So, this version of *Raga Bahar* will be categorized as *Oudava-Shadava* different *Varjya swara Raga*. There is another version of *Bahar* that has Re *swara* is *Varjya* in the *Aroha* while Dha is *Varjya* in the *Avroha*. So, this version of *Raga Bahar* will be categorized as *Shadava-Shadava* different *Varjya swara Raga* but will not come under *Prakirna Gana*. Such *Ragas* are very difficult and complicated to render but there is a peculiar beauty in the *swara* patterns generated due to alternate *Varjya swaras*.

Other few examples of this category of *Ragas* are as follows.

Raga Adana- KGa is *Varjya* in *Aroha* and KDha is *Varjya* in the *Avroha*.

Raga Deepak (*Poorvi* variation)- KRe is *Varjya* in the *Aroha* and Ni is *Varjya* in the *Avroha*.

Raga Malavi- Ni *Varjya* in the *Aroha* and *Avroha* has Dha *Varjya*.

The *Raga* generation process for this category is more or less similar as discussed in other categories and therefore, it is not repeated here.

Different *Varjya Oudava-Oudava Ragas:*

Devagiri Bilawal- This *Raga* has an unusual structure. It has Ma and Ni as *Varjya swaras* in *Aroha* while in the *Avroha* Dha and Ga are *Varjya swaras*. But the most peculiar aspect of this *Raga* is that it has both the forms of *Nishad*- Ni and KNi used in the *Avroha*. So, it has dual *swara* form of Ni in the *Raga*. The *swara* Ma necessitates the presence of KNi in the *Raga*.

Mala Rani- This is a very rare *Raga*. It has Ga and Dha as *Varjya swaras* in the *Aroha* while Mat and Ni are *Varjya swaras* in the *Avroha*.

Hema Kalyan- This is an interesting *Raga* because though it is *Oudava-Oudava* with different *Varjya swaras*, it does not have four *Varjya swaras*. It has three *Varjya swaras* because one *swara* is a shared *Varjya swara* in *Aroha* as well as *Avroha*. It has Ni and Dha as *Varjya swaras* in the *Aroha* and in the *Avroha* Ga and Ni are *Varjya swaras*. So, Ni is the shared *Varjya swara* in this *Raga*.

Different *Varjya Oudava-Shadava Ragas:*

The earlier discussed cases of *Raga Bahar* with variation belong to this category of *Oudava-Shadava* different *Varjya Swara Ragas*. There is another quite popular *Raga* called *Raga Gavati*. This *Raga* has Re and Dha as *Varjya swaras* in the *Aroha* and KNi is *Varjya swara* in the *Avroha*. This is a beautiful *Raga* due to the *Vakra* patterns generated by the missing *Varjya swaras*.

Different *Varjya Chatura-Oudava Ragas:*

There are a few very rare *Ragas* that have four *swaras* in the *Aroha* and five *swaras* in the *Avroha*. It means that there are three *swaras Varjya* in the *Aroha*. *Raga Malashri* is one such *Raga*. It is not very popular and it is also not well-known. It has Re, Mat and Dha as *Varjya swaras* in the *Aroha* while Re and Dha are *Varjya* in the *Avroha*. It means that Re and Dha are the shared *Varjya swaras* in *Aroha* and *Avroha*.

Complex Multi-Dual *Swara Ragas*

Already there has been a discussion on the ‘Augmented *Ragas*’. There are many *Ragas* where there are dual *swara*-forms of the *swaras* of the *Ragas*. If there are one or two *swaras* in a *Raga* with the dual forms then they can be rendered easily along with other *swaras*. However, if there are three or more *swaras* with dual forms then it becomes difficult to manage their relations with other *swaras*. All such *Ragas* are valid but difficult to render. Such *Ragas* are called complex multi-dual *swara Ragas* in GTIM. They are classified under *Prakirna Gana*. There is *Raga Basant Bahar* that has dual forms of four *swaras* viz. Re, Kre, Ga, KGa, Dha, KDha, Ni, KNi.

Tri-Gandhara Ragas

These *Ragas* are very rare. The best-known example of this category of *Ragas* is a *Raga Lagan Gandhar* recently created by Pandit Kumar Gandharva. This is a new *Raga*. In *Tri-Gandhara Ragas* all three *swara* forms of *Gandhara swara* are used. They are *Ati-Komal Gandhara* or *Bharata Muni's Gandhara, Komal Gandhara* or *Sadharana Gandhara* and the *Shuddha Gandhara* which was known as '*Aantar Gandhara*' in Bharata Muni's system. To make these three *Gandhara* effective and strong support is provided by having the three *swara* forms of *Nishada swara*. This is necessary because of the unique rendering of three varieties of *Gandhara* with subtle *shruti* nuances, an emotional mood is created. Three *Nishada* variations are Bharata Muni's *Nishada* or *Ati-Komal Nishada, Kaishiki Nishada* or *Komal Nishada* and *Kakali Nishad*a or *Shuddha Nishada*. Since there are totally six *swara* forms of Ga and Ni *swaras* used, this *Raga* is categorized as a *Prakirna Raga*. The structure of *Raga Lagan Gandhar* is very complex and it's a difficult *Raga* to render. *Shadja swara* is considered as the *Vadi* and *Panchama* is the *Samvadi* of this *Raga*. Ga is the primary *Anuvadi swara* and its other *swara* forms contribute to bringing out the mood of the *Raga*. It is loaded with pathos. Bharata Muni's *Gandhara* or *Ati-Komal Gandhar*a is responsible for the '*Karuna Rasa*' or the emotion of pathos. Apart from *Lagan Gandhara,* there are totally 21 *Tri-Gandhara Ragas* possible as per GTIM. Out of them, four are *Sampurna-Sampurna Ragas* with Sa-Pa *Vadi-Samvadi* pair. There are eight *Shadava-Shadava Ragas* with Sa- Pa *Vadi-Samvadi* pair and four *Ragas* with Sa-Ma *Vadi-Samvadi* pairs. There are five *Oudava-Oudava Rags* of *Tri-Gandhara* type, out of which one *Raga* has Sa- Pa *swaras* as its *Vadi-Samvadi* and four other *Ragas* have Sa-Ma *swaras* as their *Vadi-Samvadis*.

Chatuswari Ragas

The *Chatuswari Ragas* are not considered valid *Ragas*. However, few such *Ragas* are mentioned in the tradition and therefore these are classified as *Prakirna Raga*. For instance, *Raga Bhavani* is a *Raga* that has Ga, Pa, Ni *swaras Varjya* in *Aroha* as well as in the *Avroha*. This *Raga* has Sa, Re, Ma, Dha and higher Sa as *swaras*. *Vadi* is Sa and *Samvadi* is Ma. *Anuvadi* is Dha and *Anu-Anuvadi* is Re. It does not have *Anya Samvadi swara* and that makes it an incomplete *Raga* though there are two pairs of consonant *swaras* as Sa-Ma and Re-Dha. However, this *Raga* is mentioned in a few reference books on music. The GTIM takes note of such *Ragas* as a special case of *Prakirna Gana*.

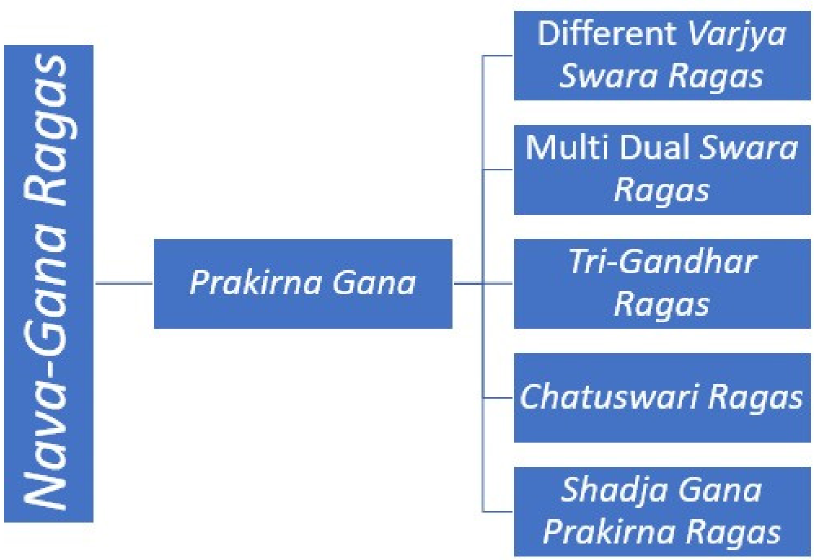
Shadja-Gana Ragas

Apart from all these types of *Ragas* there exist *Shadja Gana Ragas*. They also fall under *Prakirna Gana*. *Shadja Gana Ragas* are like regular *Ragas* but since the *swara,* Sa is a '*Nitya*' *swara*, it has omnipresence in the rendering (especially in the *Tanapura* context) and therefore, Sa as a *Vadi swara* does not make any special impact. Sa as a *Vadi* loses its significance. Therefore, *Shadja Gana Ragas* are kept in this *Gana* purely on technical grounds. It may be argued that in the absence of *Tanapura's* aural context, *Ragas* with *Shadja* as a *Vadi swara* should be worth rendering. This argument is valid and probably in the tradition before the advent of *Tanapura* such *Ragas* were prevalent. However, in contemporary Indian music where either *Tanapura* or some other instruments establish the aural context, such as *Ragas* with Sa as a *Vadi* do not make the desired impact. If a performer tries to play such *Ragas*, then the *Samvadi swara*- Pa or Ma starts showing its impact in the rendering. Therefore, in GTIM *Shadja Gana Ragas* are classified under *Prakirna Gana*.

All the *Ragas* classified under *Prakirna Gana* are valid *Ragas* as per the GTIM. These *Ragas* are generated from the seed *Ragas* in GTIM by a valid process. The *Prakirna Gana* accommodates all the possible *Ragas* which are not covered under the other eight *Ganas* and in this sense, the *Nava Gana Raga* system is comprehensive and scalable.

A Chart of *Prakirna Gana Ragas* with five categories is presented as follows.

The *Prakirna Ragas*



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PART VI
The Craft of Composing (Dha)

CHAPTER 18

A Well-Knit *Bandish*- Generating a Composition

Introduction

A *Bandish* is considered the soul of a musical performance. A *Bandish* is supposed to be a musical composition based on a particular *Raga*. It is expected that the aesthetic impact of a *Raga* gradually unfolds through the presentation of a *Bandish* and eventually, the desired aesthetic experience is evoked. The ethos or the *Rasa* of a *Raga* is articulated and expressed through a *Bandish*. A composer of a *Bandish* or the '*Vaggeyakara*' has a good understanding of the *Raga* as well as a good understanding of the craft of composing the lyrics or poetry for a *Bandish*. When a *Raga* composition is composed using lyrics or words it is called a *Bandish* but when a composition is made for playing on an instrument then it is called a '*Gat*'. The scope of the discussion in this chapter is delimited to the composition for an instrument that is a *Gat* and not a lyrical *Bandish*. The art of poetry is a vast subject in itself that goes beyond the scope of this chapter. By focusing the discussion on the composition of a *Gat*, multiple objectives are achieved. Firstly, the discussion will not digress on complex issues about the semiotics of poetry as well as many other complex issues related to prosody. Secondly, the discussion can focus on the structure of a *Gat/ Bandish* which is very important from a computational point of view. Thirdly, there exists an intricate and inherent relationship between the structure of a *Gat/ Bandish* and the *swaras* used in the *Raga*. The third aspect is very crucial for computational musicology. As already mentioned in earlier chapters four important swaras define a *Raga*. They are the *Vadi, Samvadi, Anuvadi* and *Anu-Anuvadi swaras*. How musical phrases are made up of these four types of *swaras* to articulate the ethos of a *Raga* through a *Gat/ Bandish* is a crucial factor in the analysis of a *Gat/Bandish*.

A *Gat/ Bandish* or musical composition should have four types of phrases with a relative proportion as per the GTIM approach. These are *Vadi* phrases, *Samvadi* phrases, *Anuvadi* phrases, and *Anu-Anuvadi* phrases. The relative proportion of these phrases is as follows.

- Unfettered use of *Vadi* phrases
- Only one or two *Samvadi* phrases are sufficient in the *Bandish* to maintain the *Vadi-Samvadi* balance as well as the *Poorvanga-Uttaranga* balance.
- Unrestricted use of primary *Anu-Anuvadi* and secondary *Anu-Anuvadi* phrases
- Specialized use of primary *Anuvadi* phrases
- Secondary *Anuvadi* phrases can be incidental

Computational Process of Generating a *Bandish*

A *Bandish* or a composition is generated in three stages as far as the computational process is concerned in GTIM. Here the focus of this discussion is on the computational generative process and not the process of composing a *Bandish* by a poet or the *Vaggeyakara*. Though the process is quite complex, here an attempt is made to explain it in simple language. Broadly a computational mechanism of 'generate-test-select' is used as a generative mechanism. As a general procedure, all possible *swara* phrases are generated first and then by applying relevant criteria, certain phrases are selected. This procedure is performed at least at three levels and at all levels different criteria are applied to select the *swara* phrases. If there are multiple phrases at the end of the process then one of them is selected randomly.

In the first stage, a core *Bandish* structure is developed following all *Raga*-related rules. It comprises mainly the above-mentioned *Vadi, Samvadi, Anuvadi,* and *Anu-Anuvadi swaras*-related norms along with the norms of *Graha, Nyasa, and Sama swara* norms. As a result, the number of *swara* phrases generated can be described as follows. There are at least four types of phrases such as *Graha* phrases, *Nyasa* phrases, *Sama* phrases, *Anuvadi* phrases or *Bhava* phrases. There is one more type of phrase called *Sarva* phrases. *Sarva* phrases are free phrases without any specific constraint but are generally made up of *Anu-Anuvadi* and/ or *Anuvadi swaras*. There are special connecter phrases as well that can be used to join main phrases. '*Graha'* phrases are the phrases where the first *swara* of all such phrases is the *Graha swara*. A *Bandish* begins with the *Graha* phrase. Some phrases' last *swara* happens to be a *Nyasa swara*. All such phrases are called '*Nyasa'* phrases. A *Bandish* is supposed to end with the *Nyasa* phrase. The phrases which have *PAnuvadi swara* as a member are called *Bhava* phrases. Then there are some other phrases as mentioned above that do not have such specific constraints and are called general phrases but in the GTIM they are called '*Sarva'* phrases. There is an important group of phrases whose first *swara* is a '*Sama*' *swara*. All such phrases are called '*Sama'* phrases. Normally *Vadi swara* is a '*Sama*' *swara* but in certain other situations, even *Samvadi* or the primary

Anuvadi can also become a '*Sama*' *swara* if the harmonic strength is less than the harmonic strength of the *Vadi swara*. Now very interestingly, the phrases that come before the '*Sama* phrases' have a special role to connect the '*Sama* phrase' to the phrase that precedes to '*Sama* phrase', all such possible phrases are called '*Pre-Sama*' phrases. The first level of the generative process takes care of all these factors.

In the second stage, all the above-mentioned phrases are augmented further for aesthetic impact. Certain, emotive *swaras*, *Anu-Anuvadi swaras*, and *PAnuvadi swaras* are identified from each phrase and then ornamentation operations are performed on them to make them aesthetically beautiful. These ornamentation operations are of varied types and performed in a specific way on specific types of *swaras* of the phrase. The GTIM has elaborate procedures for the ornamentation of phrases. For example, semitonal *swaras* or emotive *swaras* will have specific ornamentation operations. If there is an *Anu-Anuvadi swara* as a middle *swara* of the phrase then the ornamentation operation will be specific to that case. If a *Vadi* or *PAnuvadi swara* is the first or last *swara* of the phrase then depending on the position of the *swara* in a phrase, an ornamentation operation is executed. There are multiple but specific ways by which this ornamentation of phrases happens. Ornamentation rules for *Vakra swaras, Ardha-Varjya swaras, Durbala* (weak) *swaras* and dual-form *swaras* are thus highly specific and varied. The '*Kana*' *swaras* are also taken care of by these operations. All these operations re useful in bringing the *Gamaka* effect as well as the *Taana* effect. This stage is highly critical because it sets the flavour and mood of the *Raga*. A highly exhaustive rule base for aesthetics has been implemented in the *AI-Raga* system for this purpose.

In the third stage, the assembly operation is performed. Depending upon the *Tala* structure, the overall phrase structure, the first line of the *Bandish* is designed and the place of the '*Sama* phrase' is fixed. Certain phrases come before the '*Sama* phrase' and there are other phrases that come after the '*Sama* phrase'. The general sequence of the phrases that come before the '*Sama* phrase' starts with the '*Graha* phrase', then comes the '*Bhava* phrase' followed by the '*Sarva*' phrase and then there is a connecting phrase called 'Pre-*Sama*' phrase that is linked to the *Sama* phrase. Depending on the *Tala* structure and availability of beats some of the components are eliminated but always the first phrase is the '*Graha* phrase'. In-between phrases can be dropped. The second part phrases connect the *Sama* phrase to the *Nyasa* phrase. So, from the *Sama* phrase to the *Nyasa* phrase, a sequence of *Bhava* phrases and/ or *Sarva* phrases is generated that eventually connects to the *Nyasa* phrase. This is the way the first and most important line of a *Bandish* is constructed. Similarly, the second and/ or third lines of the *Bandish* are planned except for the fact that the first phrase in these cases need not be the *Graha* phrase. But most importantly, the *Sama* phrase has to be at the '*Sama*' beat and the last phrase has to be the *Nyasa* phrase.

A *Bandish* has two parts: the *Sthayi* part and the *Antara* part. The above-mentioned description was about constructing two or three lines for *Sthayi* of the *Bandish*. The same method is used to construct the *Antara* part of the *Bandish*. Only the difference is that the phrases of the *Antara* will be more from the upper part of the *Saptaka*. Normally, phrases for the *Sthayi* part of a *Bandish* are from the lower octave and the middle octave while the phrases for the *Antara* part are from the middle octave and the higher octave. In most of the traditional *Bandish*, the first line is used as the '*Dhruvapada*' or the '*Palupada*' which is rendered repeatedly in the performance. So, the design of the first line of the *Bandish* is very critical. Alternately there can be a separate *Dhruvapada* for a *Bandish*. In all these cases the structure and design of generation follows the above-mentioned process.

Computational Model of a *Bandish*

A computational model of the Bandish will be as follows. As it is discussed earlier at other places in this book, the 'Aural Axiomatic' paradigm is used to model the computational process of *Raga* generation. It's a system of aural or musical logic that captures all the facets of the *Raga* generation process. The following model is a generic model of *Bandish* generation irrespective of any specific *Raga*. Currently, it is implemented for instrumental music and it is yielding promising results. It works for highly complex *Ragas*. According to *Natyashastra*, *Gandharvam* (Indian music) has three dimensions- *Swara, Tala* and *Pada*. In this model for generating a *Bandish* only the *swara* dimension is taken into consideration because since it is applied for instrumental music, it does not require *Pada* or the lyrics for implementation. *Tala* part of a *Bandish* is modelled separately and is described in the last part of this book. In the present context, the *Tala* grammar is implicitly present but it is not articulated in the following description. *Tala* is implicitly embedded in the *Bandish* model itself in terms of the '*Sama*' part and 'post-*Sama*' parts of a *Bandish*. With this understanding, a computational grammar for the generation of a *Bandish* which applies to any *Raga* is generated as follows.

Here a required terminology from the music domain is used and wherever required the new terminology is introduced. So first let us write down all the rules required for this grammar. They are as follows. A *Bandish* has three parts. Here it is assumed that a typical *Bandish* has four lines split into two parts made up of two lines each. The first part is called *Sthayi* and the second part is called *Antara*. However, this norm is not very strict. A *Bandish* can have three, five, or even six lines as well. The number of lines may vary but the structure of a *Bandish* remains the same. Computational grammar is a structural description of a *Bandish*.

<Bandish> → <Dhruvapada> + <Sthayi> + <Antara>

<Dhruvapada> → <FirstLine>

<Sthayi> → <FirstLine> + <SecondLine>

<Antara> → <FirstLine> + <SecondLine>

Normally, the *Dhruvapada* is the first line of the *Sthayi* part of a *Bandish*. There can be separate *Dhruvapada* in some cases. *Dhruvapada* is repeated again and again, first in the beginning of the *Bandish*, and then after completion of the *Sthayi* part and *Antara* part while rendering a *Bandish*. A *Dhruvapada* is also known as a *Palupada*. The musical structure of a *Dhruvapada* or a *Palupada* is the same as the structure of the first line of the *Sthayi* of a *Bandish*. So first the description of the first line of a *Sthayi* is provided here.

From the musical point of view, each line of a *Bandish* can be understood in the form of an '*Aavartana*' because a *Bandish* is anchored in a *Tala* structure. An *Aavartana* is made up of '*Angas*' or '*Khandas*'. The first beat of the *Aavartana* is called '*Sama*' and the starting *Anga* with the *Sama* beat is called '*Sama Anga*' or the '*Sama Khanda*'. In actual performance, a *Bandish* need not start on the *Sama* beat or from the '*Sama Khanda*'. The starting *swara* of a *Bandish* is called '*Graha' swara* and the last *swara* is called the '*Nyasa' swara*. The *Sama* beat of an *Aavartana* can be on the *Graha swara* or it can be in between. The *swara* that coincides with the *Sama* beat is also called the *Sama swara*. For clarity of description, each line of a *Bandish* is split into two parts- the *Sama* part and the post-*Sama* part. The *Sama* part begins at the *Graha swara* and includes the *Sama Khanda*. The rest of the part of the line of a *Bandish* is called the post-*Sama* part in GTIM.

There are four types of resting points (*Nyasa swaras*) in a *Bandish*. As per the *Natyashastra*, the last *swara* of a *Bandish* is called the *Nyasa swara*. As per contemporary practices, a *Bandish* rendering ends at the last *swara* of the *Dhruvapada* so the last *swara* of the *Dhruvapada* is also treated as the *Nyasa swara*. *Natyashastra* says that the mid-point where the middle part of a *Bandish* end is called *Apanyasa*. So as per contemporary practices at the end of the second line of the *Sthayi,* the middle part of a *Bandish* is completed so the last *swara* of the *Sthayi* should be called the *Apanyasa*. *Nyasa* and *Apanyasa* are the pauses or resting *swaras*. Similarly, at the end of the first line in a *Sthayi* and at the end of the third line which is the last *swara* of the first line of the *Antara,* there is a resting *swara*. That may be called *Vinyasa*. In between there are many pauses in every line of a *Bandish*; all such pauses should be called *Sanyasa*. During Bharata Muni's times the rules for all these resting points, pauses and end points were highly strict and specific to particular *Jatis*. Analysis of contemporary music suggests that such stringent restrictions are not necessary for contemporary music. There exists a common set of *swaras* called *Nyasa swaras* which are used as all types of pauses or end *swaras*. In the following description as a part of the GTIM approach, the term *Sanyasa* is not used. But the other terms viz., *Vinyasa, Apanyasa* and *Nyasa* are used. As a norm at the end of the first line of *Sthayi* or *Antara* the resting *swara* is termed as *Vinyasa*. The end *swara* of a *Sthayi* is referred to as the *Apanyasa* and the end *swara* of the *Antara* is called *Nyasa swara*. The end *swara* of the *Dhruvapada* is also called the *Nyasa swara*. These nomenclatures are used for technical reasons. In the GTIM there is one set of *swaras* called a set of *Nyasa swaras* and all the *Vinyasa, Apanyasa* and *Nyasa swaras* are taken from this set. So, there is no difference as such. However, the terminology is used in the grammar for clarity.

Generating a *Sthayi:*
Sama Part

<SthayiFirstLine> → <SthayiFirstLineSamaPart> + <SthayiPostSamaPart>

Five possibilities for the pre-*sama*-part of the first line of the *Sthayi* are as follows. These are designed for the five, four, three, two and one *Tala Khandas* or *Angas* of the pre-*sama*-part respectively. *Sthayi* can begin even at the partial fractions of *Khandas* or *Angas* but it is not included in the following description currently for the sake of simplicity. If there are more *Tala Khandas* available then the phrase called *Sthayi Sarva* phrase will be repeatedly generated as many times as there are extra *Tala Khandas*.

The first phrase is a *Graha* Phrase. The first *swara* of this phrase is called the *Graha swara* or the take-off *swara*. For each *Raga,* there is a set of possible *Graha swaras*. This *Graha swara* will be selected from this set. Then the system will search for all the possible phrases that have the *Graha swara* as the first *swara*. GTIM has generic rules to generate a set of *Graha swaras* for a particular *Raga*.

The second phrase is a *Sthayi Bhava* phrase. It is called a *Bhava* phrase because either primary *Anuvadi* or secondary *Anuvadi swara* should be a member of this phrase. So, the system will search for all the possible phrases that have the *Bhava swara* as a member and then implement the phrase.

The third phrase is called the *Sarva* phrase which may be repeated if there are a greater number of *Tala Khandas* for the *Sthayi* line.

The fourth phrase is called the pre-*Sama* phrase because it joins the previous phrase to the *Sama* phrase.

The last phrase is called *Sthayi Sama* phrase because the first *swara* of this phrase is the *Sama swara*. The *Sama swara* is aligned with the *Sama Khanda* of the *Tala Aavartana* or a cycle of a *Tala*. In this way, *Tala* components are embedded in the description of the grammar implicitly. *Tala* provides the rhythmic foundations for the *Bandish*.

Case I for four *Khandas* or *Angas* + *Sam Khanda/ Anga*

< SthayiFirstLineSamaPart > → <SthayiGrahaPhrase> + < SthayiBhavaPhrase >+ <SthayiSarvaPhrase> + <SthayiPreSamaPhrase> + <SthayiSamaPhrase>

Case II for three *Khandas* or *Angas* + *Sam Khanda/ Anga*

< SthayiFirstLineSamaPart > → <SthayiGrahaPhrase>+< SthayiBhavaPhrase >+ <SthayiPreSamaPhrase> + <SthayiSamaPhrase>

Case III for two *Khandas* or *Angas* + *Sam Khanda/ Anga*

< SthayiFirstLineSamaPart > → <SthayiGrahaPhrase>+ <SthayiPreSamaPhrase> + <SthayiSamaPhrase>

Case IV for one *Khanda* or *Anga* + *Sam Khanda/ Anga*

< SthayiFirstLineSamaPart > → <SthayiGrahaPhrase > + <SthayiSamaPhrase>

Case V for zero Khanda or Anga + Sam Khanda/ Anga

< SthayiFirstLineSamaPart > → <SthayiSamaPhrase>

The above formalism suggests that there are following three phrases available for selection in the given sequence and depending on the desired number of *Khandas* they are chosen. The three phrases are as follows:

<SthayiGrahaPhrase > →

< SthayiBhavaPhrase > →

<SthayiSarvaPhrase > →

After that the pre-*Sama* phrase is important because it acts as a connector between the previously described phrases and the *Sama*-phrase.

<SthayiPreSamaPhrase> →

At the end of this part is the *Sama*-phrase.

<SthayiSamaPhrase> →

Generating a *Sthayi:* Post-*Sama* Part

Three possibilities for the post-*Sama*-part of the first line of the *Sthayi* are as follows. These are designed for the three, two and one *Tala Khandas/ Angas* of the post-*Sama*-part respectively. If there are more *Tala Khandas* available then the first phrase called *Sthayi Sarva* phrase will be repeated as many times as there are extra *Tala Khandas*. The second phrase is a *Sthayi Bhava* phrase. The last phrase is called the *Sthayi Vinyasa* phrase. When it is a part of the *Dhruvapada* then it is called *Dhruva Nyasa* phrase. It is called either *Vinyasa* or *Nyasa* phrase because the last *swara* of this phrase is resting. This resting *swara* is chosen from a *Raga*-specific set of *Nyasa swaras* and then the system searches for all the possible phrases that have this resting *swara* as the last *swara*.

Case I for at least two *Khanda or Anga + Nyasa/ Vinyasa Khanda/ Anga*

<SthayiPostSamaPart> → <SthayiSarvaPhrase> + < SthayiBhavaPhrase> +
< SthayiVinyasaPhrase>

Case II for one *Khanda or Anga + Nyasa/ Vinyasa Khanda/ Anga*

<PostSamaPart> → < SthayiBhavaPhrase> + < SthayiVinyasaPhrase>

Case III for at zero *Khanda or Anga + Nyasa/ Vinyasa Khanda/ Anga*

<PostSamaPart> → < SthayiVinyasaPhrase>

As shown in the first case above, before the *Vinyasa* phrase there can be any number of *Khandas* available. The last *Khand/ Anga* is reserved for the *Vinyasa* phrase and the last but one *Khanda/ Anga* (if any) is reserved for the *Bhava* phrase. The *Sarva* phrase can be used for all the remaining additional *Khandas/ Angas* if any.

<SthayiSarvaPhrase> →

< SthayiBhavaPhrase> →

< SthayiVinyasaPhrase> →

Following description is about the second line of the *Sthayi* of the *Bandish*.

<SthayiSecondLine> →
<SthayiSecondLineSamaPart>+<SthayiPostSamaPart>

The description for the *Sama* part for the second line is as follows. All the description for the variables in the following description is almost the same as the description of the first line. Only in the *Sama* part of the description, the first phrase is a *Graha* Phrase. This phrase is different. Here the *Graha swara* is decided based on the *Vinyasa swara*. *Vinyasa swara* is the last *swara* of the first line of the *Sthayi*. The second line of the *Sthayi* should begin with this *Vinyasa swara* to maintain the continuity between the first line and the second line. The *Vinyasa swara* is the default *Graha swara* for the *Sthayi* second line and accordingly, the system selects the possible *Graha phrases* for the second line. Optionally, the consonant *swara* of the *Vinyasa swara* can be used as the *Graha swara* here. Rest of the phrases for the *Sthayi* second line are generated in the same manner as in the case of the *Sthayi* first line.

< SthayiSecondLineSamaPart > → <SthayiGrahaPhrase> +
< SthayiBhavaPhrase >+ <SthayiSarvaPhrase> + <SthayiPreSamaPhrase> +
<SthayiSamaPhrase>

< SthayiSecondLineSamaPart > → <SthayiGrahaPhrase>+
< SthayiBhavaPhrase >+ <SthayiPreSamaPhrase> + <SthayiSamaPhrase>

< SthayiSecondLineSamaPart > → <SthayiGrahaPhrase>+
<SthayiPreSamaPhrase> + <SthayiSamaPhrase>

< SthayiSecondLineSamaPart > → <SthayiGrahaPhrase > +
<SthayiSamaPhrase>

< SthayiSecondLineSamaPart > → <SthayiSamaPhrase>

<SthayiGrahaPhrase> →

< SthayiBhavaPhrase > →

<SthayiSarvaPhrase> →

<SthayiPreSamaPhrase> →

<SthayiSamaPhrase> →

The description for the second line post-*Sama* part is as follows. This description is also very similar to the description of the *Sthayi* first line. There is a slight change in the last phrase though. At the end of the second line of the *Sthayi,* there is a larger pause called *Apanyasa*. Although the *swara* for *Apanyasa* swara is chosen from the same standard *Raga*-specific set of *Nyasa swaras*.

<SthayiSecondLinePostSamaPart> → <SthayiSarvaPhrase> +
< SthayiBhavaPhrase> + < SthayiApanyasaPhrase>

<SthayiSecondLinePostSamaPart> → < SthayiBhavaPhrase> +
< SthayiApanyasaPhrase>

<SthayiSecondLinePostSamaPart> → < SthayiApanyasaPhrase>

<SthayiSarvaPhrase> →

< SthayiBhavaPhrase> →

< SthayiVinyasaPhrase> →

Generating an *Antara:* *Sama* Part

The rules are the same for the *Antara* part of the *Bandish*. Structurally there is no difference between the set of rules for the *Sthayi* and the set of rules for the *Antara*. Few variables are changed appropriately.

These are the rules for the first line of the *Antara* part of the *Bandish*.

<AntaraFirstLine> → <AntaraFirstLineSamaPart> + <AntaraPostSamaPart>

Following is the rule description for the *Sama* Part of the first line of the *Antara*.

<AntaraFirstLine> → <AntaraFirstLineSamaPart> + <AntaraPostSamaPart>

Following is the rule description for the *Sama* Part of the first line of the *Antara*.

< AntaraFirstLineSamaPart > → <AntaraGrahaPhrase> + < AntaraBhavaPhrase > + <AntaraSarvaPhrase> + <AntaraPreSamaPhrase> + <AntaraSamaPhrase>

< AntaraFirstLineSamaPart > → <AntaraGrahaPhrase> +< AntaraBhavaPhrase > + <AntaraPreSamaPhrase> + <AntaraSamaPhrase>

< AntaraFirstLineSamaPart > → <AntaraGrahaPhrase> + <AntaraPreSamaPhrase> + <AntaraSamaPhrase>

< AntaraFirstLineSamaPart > → <AntaraGrahaPhrase > + <AntaraSamaPhrase>

< AntaraFirstLineSamaPart > → <AntaraSamaPhrase>

<AntaraGrahaPhrase> →

< AntaraBhavaPhrase > →

<AntaraPreSamaPhrase> →

<AntaraSamaPhrase> →

Generating an *Antara:* Post-*Sama* Part

Following is the *Antara* Post *Sama* Part first line description.

<AntaraPostSamaPart> → <AntaraSarvaPhrase> + < AntaraBhavaPhrase> + < AntaraVinyasaPhrase>

<PostSamaPart> → < AntaraBhavaPhrase> + < AntaraVinyasaPhrase>

<PostSamaPart> → < AntaraVinyasaPhrase>

Following description is about the second line of the *Antara* of the *Bandish*.

<AntaraSecondLine> →
<AntaraSecondLineSamaPart>+<AntaraPostSamaPart>

Initially, there is a rule description of the *Sama* Part of the *Antara*. Here again the *Graha swara* for the second line is the *Vinyasa swara* of the first line by default to preserve the continuity between these two lines. Optionally, consonant *swaras* of the *Vinyasa swaras* can be used as *Graha swara*.

< AntaraSecondLineSamaPart > → <AntaraGrahaPhrase> +
< AntaraBhavaPhrase >+ <AntaraSarvaPhrase> + <AntaraPreSamaPhrase> +
<AntaraSamaPhrase>

< AntaraSecondLineSamaPart > → <AntaraGrahaPhrase>+
< AntaraBhavaPhrase >+ <AntaraPreSamaPhrase> + <AntaraSamaPhrase>

< AntaraSecondLineSamaPart > → <AntaraGrahaPhrase>+
<AntaraPreSamaPhrase> + <AntaraSamaPhrase>

< AntaraSecondLineSamaPart > → <AntaraGrahaPhrase > +
<AntaraSamaPhrase>

< AntaraSecondLineSamaPart > → <AntaraSamaPhrase>

<AntaraGrahaPhrase> →

< AntaraBhavaPhrase > →

<AntaraSarvaPhrase> →

<AntaraPreSamaPhrase> →

<AntaraSamaPhrase> →

Description for the second line post-*Sama* part for *Antara* follows. There is a slight change in the last phrase though. At the end of the second line of the *Antara,* there is a larger pause called *Nyasa*. So, the last Phrase is called *Antara Nyasa* Phrase. The *swara* for *Nyasa* is chosen from the same standard *Raga*-specific set of *Nyasa swaras*.

<AntaraPostSamaPart> → <AntaraSarvaPhrase> + < AntaraBhavaPhrase> + < AntaraNyasaPhrase>

<PostSamaPart> → < AntaraBhavaPhrase> + < AntaraNyasaPhrase>

<PostSamaPart> → < AntaraNyasaPhrase>

Thus, the rule base for *Bandish* generation with major variables is complete here.

The undefined variables in each rule can be defined further so that they will become comprehensible. In this regard, while defining the *swara* phrases in the next chapter a formal description of *Graha* phrases, *Bhava* phrases, *Sarva* phrases, *Sama* phrases, pre-*Sama* phrases, and connecter phrases is provided. That can be appropriately re-purposed for the *Sthayi* parts and the *Antara* parts of the *Bandish*. For instance, there can be a *SthayiGraha*Phrase or there can be an *AntaraGraha*Phrase. The same approach can be used for *Bhava* phrases, *Sarva* phrases, *Sama* phrases and so on. The description for the Bandish generation is completed thus.

CHAPTER 19

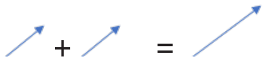
The Warps and the Wefts- Phrase Generation

Introduction

The formal structure of a *Bandish* is already established in the previous chapter. In that model, there were a few undefined variables at the end. These variables represent the *swara* phrases. For any musical rendering, it is necessary to generate phrases of *swaras* that are used while composing a *Bandish* or rendering a *Raga*. Phrases are not generated randomly. Phrases are generated by following the rules of the *Raga*. For instance, if in a particular *Raga*, if a particular *swara* is *Varjya* in the *Aroha* then that *swara* cannot be used in the *Aroha swara* phrases. A phrase is an ordered sequence of *swaras* and so it can have multiple *swaras*. There can be a phrase of single *swara*, two *swaras*, three *swaras*, four *swaras* and so on. Initially, one-*swara* phrases, two-*swara* phrases, three-*swara* phrases and four-*swara* phrases are generated as per the GTIM by following the rules of the *Raga*. Then these phrases are joined to form slightly larger phrases of five *swaras*, six *swaras*, seven *swaras* and eight *swaras*. For generating a *Bandish* (musical composition) generally, the system does not need larger phrases. Longer phrases are required for generating *Aalaps* (*Raga* exploratory phrases), and *Taanas* (ordered sequences of *swaras* with ornamentation), while rendering the *Vistara* (*Raga* elaboration) of the *Raga*. The process of phrase generation can be articulated as follows.

Swara phrases that are used for a *Bandish* generation are of four types. According to tradition, a *swara* phrase can be *Arohi* which means all *swaras* in the phrase are in ascending order. The other pattern is of *Avrohi* phrases where all the *swaras* in a phrase are in descending order. Some swara phrases initially use ascending order and then turn downwards using descending pattern. The fourth type is the opposite of it that is first there is a descending order and then the phrase ascends.

***Arohi-Arohi* phrase**



***Avrohi-Avrohi* phrase**

***Arohi-Avrohi* phrase**

***Avrohi-Arohi* phrase**

There can be *swara* phrases that skip one or two *swaras* or jump from one *swara* to another. These are called *Meend* phrases that are discussed at the appropriate place. There can be a single *swara* phrase where a single *swara* is stretched for a certain duration and there can be a single *swara* phrase that repeats the same *swara* again and again for a certain duration. Apart from these types of phrases, there are special phrases called *Alamkara* (ornamentation) phrases where ornamental repetitive patterns are generated. These phrases add beauty to the *Raga* rendering and therefore are very important.

Computing Phrases

Let us assume that there is a finite set R_A of *Arohi swaras*. This is a set of *Raga*-specific *Arohi swaras* arranged in a sequential manner. This set may be extendable to higher and lower octaves. So, the *swaras* from the lower octave, the middle octave, and the higher octaves can be used for generating various phrases. The GTIM has provision of processing up to nine octaves because *Meend* phrases may involve long jumps across octaves and long *Taanas* can run across all the octaves- normally three octaves. We can assume a similar set R_D that stands for the *Raga*-specific *Avrohi swaras* that are arranged in a descending order. Members of set R_A and members of set R_D need not be the same.

This set of *Arohi swaras* of a *Raga* may be represented as

$R_A = \{a_1, a_2, a_3, \ldots a_k\}$

Similarly, set of *Avrohi swaras* is represented as

$R_D = \{d_1, d_2, d_3, \ldots d_k\}$

Thus, the complete set of all *swaras* in a *Raga*, R, can be represented as $R_A \cup R_D$.

This agrees with the precept that a *Raga* is a union of *Aroha* and *Avroha*.

With this basic formal information about the *Raga*, we can have a function for making a single *swara* phrases for the *Raga* as follows

$fre_1(a_k) = \{[a_1], [a_2], [a_3], \ldots [a_k]\}$ Let us call this a set A_I

then we can have a function called fre_2 for concatenation of every consecutive two *swaras* as follows

$fre_2(a_k) = \{[a_1, a_2], [a_2, a_3], \ldots [a_{k-1}, a_k]\}$ this could be a set A_{II}

Similarly, there can be a function for three *swara*-phrases as

$fre_3(a_k) = \{[a_1, a_2, a_3], [a_2, a_3, a_4], \ldots [a_{k-2}, a_{k-1}, a_k]\}$ and this can be set A_{III}

and a function for four *swara*-phrases as

$fre_4(a_k) = \{[a_1, a_2, a_3, a_4], [a_2, a_3, a_4, a_5], \ldots [a_{k-3}, a_{k-2}, a_{k-1}, a_k]\}$ and this can be set A_{IV}

So, we have four sets A_I, A_{II}, A_{III} and A_{IV} for *Arohi* phrases generated from the set R_A by using these four functions. Similarly, we can generate phrases for *Avrohi* order or descending order from the set R_D which has *Avrohi swaras* which is also extendable to higher and lower octaves. By using the similar approach, we can get as many number of *Arohi* sets and *Avrohi* sets of phrases that may cover the entire range of all the octaves useful for generating music. For composing a *Bandish* or for rendering a *Raga*, sequential phrases are very important. Phrases up to four *swaras* are good enough for generating all kinds of longer phrases involving a greater number of *swaras*.

With these four *Arohi* sets A_I, A_{II}, A_{III}, A_{IV} - a set of all these four sets put together can be called a set $U_A = \{A_I \cup A_{II} \cup A_{III} \cup A_{IV}\}$. Similarly, four *Avrohi* sets D_I, D_{II}, D_{III} and D_{IV} comprise of another set called $U_D = \{D_I \cup D_{II} \cup D_{III} \cup D_{IV}\}$. With these two sets we can generate a good database for initial sequential phrases. These initial phrases are useful for generating longer sequential phrases and mixed phrases involving ascending and descending movements of *swaras*. Similarly, *Meend* phrases involving jumps from one *swara* to another by skipping in-between *swaras* can also be generated from these sets. There exists one more category of phrases called '*Alamkara*' phrases. The set R_A and the set R_D are useful to generate *Alamkara* phrases also.

Each phrase of each set cannot be concatenated with every phrase of every other set because the first and the last *swaras* of joining phrases may not match in musically significant way. If they do not match in musically appropriate way then the newly generated phrase will sound musically dis-jointed. Thus, we need certain musical criteria for concatenation of phrases. Musically significant criteria to achieve this is that if phrase X is joining to the phrase Y, then the last *swara* of phrase X and the first *swara* of the phrase Y should adhere to certain norms.

1. The first norm is that the last *swara* of the phrase X and the first *swara* of the phrase Y should be next to each other in the order of a sequence, whether it is ascending or descending. This norm is useful for generating sequential phrases.
2. The second norm is that the last *swara* of X and the first *swara* of Y should adhere to the aural inference rules called LMLs. All the LMLs are already discussed in details in earlier chapters of this book so the description is not repeated here.
3. For non-sequential phrases, more specifically, these *swaras* should adhere to the LML SG, LML SKG, LML SD, and LML SKD for generating *Meend* phrases having small jumps. LMLs like LML SP, LML SM, and LML SS' are useful for generating long *Meends*.

With adherence to the above-mentioned LMLs with the help of *Arohi* set U_A and *Avrohi* set U_D it is possible to generate all the types of simple sequential *swara* phrases, mixed phrases and *Meend* phrases. Sequential phrases, mixed phrases and *Meend* phrases are generated separately by using different functions. This process results into a comprehensive database for a *Raga* because all these phrases are generated from *swaras* used in a specific *Raga*. The central theme of GTIM is the generative nature of Indian music. It is applicable for building a database for the required *swara* phrases for a *Bandish*. As per the GTIM philosophy, there is no need of any pre-existing databases. All the required data is generated by the *AIRaga* systems.

The phrase generation process can be formalized as follows.

Initially, two functions can be defined as FIRST-f and LAST-l suggesting the first member and the last member of the *swara*-phrases respectively.

FIRST-f ([sa, re, ga]) = sa and

LAST-l ([sa, re, ga]) = ga

Sequential and Mixed Phrase Generation

We recall that we have assumed that there is an original set of *Arohi swaras* R_A for a specific *Raga* where *swaras* are arranged in an ascending order.

$R_A = \{a_1, a_2, a_3, \dots a_{k-1}, a_k\}$

By using the operations fre_1, fre_2, fre_3, fre_4, sets of *Arohi swara*-phrases are generated. The set U_A is made up of all such sets of *Arohi swara*-phrases.

Similarly, for *Avrohi swaras* of the *Raga* there is a set R_D

$R_D = \{d_1, d_2, d_3, \ldots d_{k-1}, d_k\}$

By using the operations fre_1, fre_2, fre_3, and fre_4, sets of *Avrohi swara*-phrases are generated. The set U_D is made up of all such sets of *Avrohi swara*-phrases.

Now there are four possibilities.

1. We can generate *Arohi-Arohi* phrases by joining phrases of two members sets of U_A.
2. The second possibility is of *Arohi-Avrohi* mixed *swara* phrases by taking first member set from U_A and the second from U_D.
3. Thirdly, *Avrohi-Avrohi* phrases from U_D sets.
4. Fourthly, we can have *Avrohi-Arohi* mixed phrase by using first set from U_D and the second from U_A.

Let us assume two sets of phrases A_m and A_n such that $\varphi_m \in A_m$ and $\varphi_n \in A_n$ and for each of the above-mentioned scenarios they can be represented as follows.

For the first case $A_m \in U_A$ and $A_n \in U_A$. {Associated Function: - FreSeqAA}

For the second case $A_m \in U_A$ and $A_n \in U_D$. {Associated Function: - FreSeqAM}

For the third case $A_m \in U_D$ and $A_n \in U_D$. {Associated Function: - FreSeqDD}

For the fourth case $A_m \in U_D$ and $A_n \in U_A$. {Associated Function: - FreSeqDM}

With these assumptions we can define the associated functions to these four cases respectively, that will generate all simple sequential *swara* phrases such as *Arohi-Arohi* as well as mixed *swara* phrases involving *Arohi-Avrohi* mixed phrases or *Avrohi-Avrohi* and *Avrohi-Arohi* mixed phrases.

FreSeqAA $(\varphi_m, \varphi_n) = \{[\varphi_{m+n}]$ where m, n $| \varphi_m \in A_{m,}\ \varphi_n \in A_n$ and LAST-l $(\varphi_m) = a_k$, FIRST-f $(\varphi_n) = a_{k+1}\}$ where $\exists k$ such that $0 < k < 5$

FreSeqAM $(\varphi_m, \varphi_n) = \{[\varphi_{m+n}]$ where m, n $| \varphi_m \in A_{m,}\ \varphi_n \in A_n$ and LAST-l $(\varphi_m) = a_k$, FIRST-f $(\varphi_n) = a_{k-1}\}$ where $\exists k$ such that $0 < k < 5$

FreSeqDD $(\varphi_m, \varphi_n) = \{[\varphi_{m+n}]$ where m, n $| \varphi_m \in A_{m,}\ \varphi_n \in A_n$ and LAST-l $(\varphi_m) = a_k$, FIRST-f $(\varphi_n) = a_{k\_1}\}$ where $\exists k$ such that $0 < k < 5$

FreSeqDM $(\varphi_m, \varphi_n) = \{[\varphi_{m+n}]$ where m, n $| \varphi_m \in A_{m,}\ \varphi_n \in A_n$ and LAST-l $(\varphi_m) = a_k$, FIRST-f $(\varphi_n) = a_{k+1}\}$ where $\exists k$ such that $0 < k < 5$

The first case:

The following function generates *Arohi-Arohi* sequential joint phrases.

FreSeqAA $(\varphi_m, \varphi_n) = \{[\varphi_{m+n}]$ where m, n $| \varphi_m \in A_{m,}\ \varphi_n \in A_n$ and LAST-l $(\varphi_m) = a_k$, FIRST-f $(\varphi_n) = a_{k+1}\}$ where $\exists k$ such that $0 < k < 5$

For example, if the set U_A = {sa, re, ga, ma, pa, dha, ni} is the original *Arohi* metaset and there are two phrases φ_m and φ_n such that $\varphi_m \in A_m$, $\varphi_n \in A_n$ and φ_m = [sa, re, ga] and φ_n = [ma, pa, dha] then with the above function FreSeqAA we will get φ_{m+n} = [sa, re, ga, ma, pa, dha] which is an *Arohi-Arohi* joint phrase.

The second case:

FreSeqAM $(\varphi_m, \varphi_n) = \{[\varphi_{m+n}]$ where m, n | $\varphi_m \in A_m$, $\varphi_n \in A_n$ and LAST-l $(\varphi_m) = a_k$, FIRST-f $(\varphi_n) = a_{k-1}\}$ where $\exists k$ such that $0 < k < 5$

With the above function we can get *Arohi-Avrohi* mixed *swara* phrase if the values are changed as follows. For example, from two *swara* phrases φ_m = [sa, re, ga] and φ_n = [ma, ga, re] we will get φ_{m+n} = [sa, re, ga, ma, ga, re].

The third case:

FreSeqDD $(\varphi_m, \varphi_n) = \{[\varphi_{m+n}]$ where m, n | $\varphi_m \in A_m$, $\varphi_n \in A_n$ and LAST-l $(\varphi_m) = a_k$, FIRST-f $(\varphi_n) = a_{k-1}\}$ where $\exists k$ such that $0 < k < 5$

With this function we can generate simple *Avrohi-Avrohi* sequential *swara* phrases. For example, from two *swara* phrases φ_m = [dha, pa, ma] and φ_n = [ga, re, sa] we will get φ_{m+n} = [dha, pa, ma, ga, re, sa] which is an *Avrohi-Avrohi* joint phrase.

The fourth case:

FreSeqDM $(\varphi_m, \varphi_n) = \{[\varphi_{m+n}]$ where m, n | $\varphi_m \in A_m$, $\varphi_n \in A_n$ and LAST-l $(\varphi_m) = a_k$, FIRST-f $(\varphi_n) = a_{k+1}\}$ where $\exists k$ such that $0 < k < 5$

With this function we can get *Avrohi-Arohi* mixed *swara* phrases. For example, from two *swara* phrases φ_m = [dha, pa, ma] and φ_n = [ga, ma, pa] we will get φ_{m+n} = [dha, pa, ma, ga, ma, pa].

With these four functions we can generate all the types of sequential *swara* phrases and mixed *swara* phrases that are useful for *Bandish* generation as well as *Raga* rendering.

Using these four functions variety of sequential phrases and mixed phrases can be generated. If we operate these functions on metasets A_{II} and A_{III} then five *swara* phrases will be generated. With metaset A_{II} on itself will generate four *swara* phrases and with set A_{III} on itself we will generate six *swara* phrases. All these are

Arohi-Arohi sequential phrases. Similarly using D_I, D_{II}, D_{III} metasets we can have *Avrohi-Avrohi* sequential phrases. Variety of mixed phrases with the help of these functions by operating on one *Arohi* set and another *Avrohi* set and vice versa. For example, taking set A_{II} and D_{II} we get mixed phrases that have first part *Arohi* and the later part *Avrohi*. If we reverse the order as set D_{II} and A_I then we will get phrases that have first part *Avrohi* and the latter half *Arohi.* All these phrases are sequential phrases and simple mixed phrases. Both the types of *swara* phrases are very important in generating a *Bandish* and rendering a *Raga*.

Generating *Meend* Phrases

The *Meend* phrases are characteristic of Indian music. When there is a small or long jump between two *swaras* of a phrase, such a phrase is called a *Meend* phrase. *Meend* phrases are normally small having two or three *swaras*. There can be a *Meend* between two *swaras* that are in different octaves also. To generate *Meend* phrases, therefore, a special set of LMLs is assumed. Let us assume LMLMND = {sg, skg, sd, skd, sp, sm, ss'} is the set of LMLs where

airMND $\in$ LMLMND

Now keeping in mind, the above-discussed four scenarios, using this set of LMLs we can generate four types of *Meend* phrases, namely, *Arohi-Arohi Meend* phrases, *Arohi-Avrohi Meend* phrases, *Avrohi-Avrohi Meend* phrases and *Avrohi-Arohi Meend* phrases. For this we require to define a new function as follows.

This function fulfills the requirements of the fist two cases that generate *Arohi-Arohi Meend* phrases and *Arohi-Avrohi Meend* phrases.

freMndAM (a_m, a_n) = {[a_{m+n}] where m, n | LAST-l (a_m)= a_s, FIRST-f (a_n) = a_p, airMND (a_s) = a_p}

With minor changes this function fulfills the requirements of the third and fourth cases that generate *Avrohi-Avrohi Meend* phrases and *Avrohi-Arohi Meend* phrases.

freMndDM (a_m, a_n) = {[a_{m+n}] where m, n | LAST-l (a_m)= a_p, FIRST-f (a_n) = a_s, airMND (a_p) = a_s}

For generating *Meends* we need limited number of sets having only one or two *swara* members in a phrase. So let us have sets A_I and A_{II} for *Arohi-Arohi Meends* and sets D_I and D_{II} for *Avrohi-Avrohi Meends*. Even if we take longer phrases, *Meends* can be generated but normally in musical performance *Meends* bring in special musical flavor to the *Raga* and so *Meend swaras* are the focus.

If the above-mentioned functions are operated on set A_I, we will get *Arohi-Arohi*

Meends having two *swaras*. These functions if operated on A_I and A_{II} then we will get *Arohi-Arohi Meends* starting from single *swara* and then joining to the two *swara* phrase. If it is operated switching the order of the sets as set A_{II} and set A_I then first part will have two *swaras* and then the *Arohi-Arohi* jump or *Meend* will begin from the second *swara* to the last *swara*. Similarly, variety of *Meends* can be generated with various operations. If the function is operated on sets D_I and D_{II} then we will generate variety of *Avrohi-Avrohi Meends*. As already mentioned, some of the *Meends* would be across the octaves because all these *Arohi* and *Avrohi* sets are extendable to other octaves.

Generating *Alamkara* Phrases

So far three types of *swara* phrases are generated- simple sequential phrases that are either *Arohi* or *Avrohi*, mixed *swara* phrases that involve *Arohi-Avrohi* or *Avrohi-Arohi* combinations and the *Meend swara* phrases that are characteristic of *Raga* music involving jumps from one *swara* to another by skipping in between *swaras*. There exists one more important category of *swara* phrases called *Alamkara* phrases. These are typically used for ornamentation while rendering a *Raga*. In a limited way these phrases are also useful in composing a *Bandish*.

Let us assume that there is a finite set A of *Arohi swaras* that means *swaras* are organized in an ascending order. This is a set of Raga-specific *Arohi swaras* arranged in a sequential manner. This set may be extendable to higher and lower octaves. So, the *swaras* from the middle octave, the higher octaves and the lower octaves can be used for generating various phrases. We can assume a similar set D that stands for the *Raga*-specific *Avrohi swaras* that are arranged in a descending order. Members of set A and members of set D need not be the same. The GTIM based *AIRaga* system has provision of processing up to nine octaves that includes four lower octaves, one middle octave and four higher octaves. *Alamkara* phrases involve repetition of one or more *swaras* to create a new phrase and at times one or more *swaras* are skipped to generate a new phrase. *Alamkara* is a *swara* pattern created by repeating or skipping the *swaras* in a regular sequential *swara*-phrase. There exists a logic of repetition and skipping the *swara* and the same logic is followed in ascending and descending order across the multiple octaves for generating new phrases. There can be small *Alamkara* phrases that may involve two to three *swaras* and distinct ornamental patterns. There can be longer *Alamkara* phrases that can involve normally four or more *swaras* with complex patterns of repetition and skipping of *swaras*. Number of *Alamkaras* are innumerable. However, we can study few basic patterns of *Alamkaras* that will give us fairly good idea of how to generate such *Alamkaras*.

Let us assume a set of *Arohi swaras* of a *Raga* that may be represented as

$A = \{a_1, a_2, a_3, \ldots a_k\}$

Similarly, set of *Avrohi swaras* is represented as

$D = \{d_1, d_{2, \ldots} d_k\}$

We can have function $freAlm_{11}$ for repeating every *swara* twice and generate new phrases as follows

$freAlm_{11}(a_k) = \{[a_1, a_1], [a_2, a_2], [a_3, a_3], \ldots [a_k, a_k]\}$

We can have function $freAlm_{111}$ for repeating every *swara* thrice and generate new phrases as follows

$freAlm_{111}(a_k) = \{[a_1, a_1, a_1], [a_2, a_2, a_2], [a_3, a_3, a_3], \ldots [a_k, a_k, a_k]\}$

then we can have simple functions involving two *swaras* for repeating consecutive pairs of *swaras* twice as follows

$freAlm_{12}(a_k) = \{[a_1, a_2], [a_2, a_3], [a_3, a_4], \ldots [a_{k-1}, a_k]\}$ or as follows

$freAlm_{1212}(a_k) = \{[a_1, a_2, a_1, a_2], [a_2, a_3, a_2, a_3], \ldots [a_{k-1}, a_k, a_{k-1}, a_k]\}$

With this approach many patterns of ornamentation of *swaras* are possible. In North Indian music many such patterns are recognized and taught to the students of music and they are called *Alamkaras*. In Carnatic music these patterns are called '*Jatiswaram*'. Apart from these standard patterns many more patterns can be generated. Generative formalisms for some of these patterns of ornamentation are shown below.

There can be a function for three *swaras* phrases where the first *swara* is repeated at the end of the phrase. It will look like as follows.

$FreAlm_{121}(a_k) = \{[a_1, a_2, a_1], [a_2, a_3, a_2], \ldots [a_{k-2}, a_{k-1}, a_{k-2}]\}$

Another pattern would be slightly complex as follows.

$FreAlm_{132}(a_k) = \{[a_1, a_3, a_2], [a_2, a_4, a_3], \ldots [a_{k-3}, a_{k-1}, a_{k-2}]\}$

There can be a pattern where you can skip a *swara* and an ornamental phrase is generated with the help of following function.

$FreAlm_{13}(a_k) = \{[a_1, a_3], [a_2, a_4], \ldots [a_{k-3}, a_{k-1}]\}$

A quite complicated function for three and four *swara* phrases will be as follows where alternate *swaras* are skipped and a new order is created. Such *Alamkaras* are quite complicated but they generate beautiful patterns.

This uses three *swaras* as follows.

$FreAlm_{1321}(a_k) = \{[a_1, a_3, a_2, a_1], [a_2, a_4, a_3, a_2], \ldots [a_{k-1}, a_{k-2}, a_{k-3}, a_{k-1}]\}$

The following uses four *swaras*.

$FreAlm_{1324}(a_k) = \{[a_1, a_3, a_2, a_4], [a_2, a_4, a_3, a_5], \ldots [a_{k-4}, a_{k-2}, a_{k-3}, a_{k-1}]\}$

By using same four *swaras* such as [sa, re, ga, ma] very interesting patterns of *Alamkaras* can be generated as shown below.

$FreAlm_{1234}(a_k) = \{[a_1, a_2, a_3, a_4], [a_2, a_3, a_4, a_5], \ldots [a_{k-4}, a_{k-3}, a_{k-2}, a_{k-1}]\}$

$FreAlm_{4123}(a_k) = \{[a_4, a_1, a_2, a_3], [a_5, a_2, a_3, a_4], \ldots [a_{k-1}, a_{k-4}, a_{k-3}, a_{k-2}]\}$

$FreAlm_{3124}(a_k) = \{[a_3, a_1, a_2, a_4], [a_4, a_2, a_3, a_5], \ldots [a_{k-2}, a_{k-4}, a_{k-3}, a_{k-1}]\}$

$FreAlm_{4321}(a_k) = \{[a_4, a_3, a_2, a_1], [a_5, a_4, a_3, a_2], \ldots [a_{k-1}, a_{k-2}, a_{k-3}, a_{k-4}]\}$

By skipping one *swara* a beautiful *Alamkara* pattern can be generated as follows by using the set of *swaras*. Here the 2nd *swara* is skipped.

$FreAlm_{1\text{-}34}(a_k) = \{[a_1, -, a_3, a_4], [a_2, -, a_4, a_5], \ldots [a_{k-4}, -, a_{k-2}, a_{k-1}]\}$

Similarly, by skipping the 2nd *swara* and replacing it by first *swara* an interesting *Alamkara* pattern can be generated as follows from the above *swaras* as follows.

$FreAlm_{1134}(a_k) = \{[a_1, a_1, a_3, a_4], [a_2, a_2, a_4, a_5], \ldots [a_{k-4}, a_{k-4}, a_{k-2}, a_{k-1}]\}$

The above description gives a good enough idea about the nature of *Alamkara* phrases that are used for ornamentation. All the standard *Alamkara* patterns given in the text books of music are not described here for the sake of brevity.

The above description was for the *Arohi Alamkara* phrases. By using the above functions, we can generate *Avrohi Alamkara* phrases for the descending order from the set D which has *Avrohi swaras* which is also extendable to higher and lower octaves. By using the similar approach, we can get variety of *Arohi* and *Avrohi Alamkara* phrases.

It must be noted that some of the above functions operate on two *swara* phrases, some of them operate on three or four *swara* phrases. There can be functions that can work on longer phrases. But the functions that work on two or three *swara* phrases can be used for generating partial *Alamkara* phrases. For instance, if there is a phrase comprising of five *swaras* then it is possible to generate variations on such a phrase by using small functions on parts of this phrase. Let us take an example, if there is a phrase X = [sa, re, ga, ma, pa] then we can select first two *swaras* of this phrase [sa, re] and some of the above-mentioned functions can be operated to generate many *Alamkara* phrases from this selected part. With this operation variations such as [sa, re, sa, re] or [sa, sa, re, re] can be generated. Then these variations can be joined to the original phrase and new extended phrases can be generated. In this case these extended variations will be [sa, re, sa, re, sa, re, ga, ma, pa] and [sa, sa, re, re, sa, re, ga, ma, pa]. Here the variations are prefixed to the original phrase. In the same manner postfix variations are also possible. If we take last two *swara* [ma, pa] for variations then using the same functions we will get postfix variations as [sa, re, ga, ma, pa, ma, pa, ma, pa] and [sa, re, ga, ma, pa, ma, ma, pa, pa]. Such applications of above- discussed functions are very useful in extending the existing phrases, in the beginning or at the end. Such extended *Alamkara* phrases are considered as 'Beauty' phrases in the *AI-Raga* system because they add an element of beauty to the original phrases. Such phrases are splendidly used while generating a *Bandish*. The functions that work on large number of *swaras* are useful in generating *Aalaps* and *Taanas* in *Raga Vistara*.

Phrases for *Gat/ Bandish* Generation and *Raga Vistara*

Above paragraphs provide a formal description of *krama* (sequential) phrases such as *Arohi, Avrohi* and *Mishra* that is mixed phrases of *swaras* as well as the *Meend* phrases and the *Alamkara* phrases. All these phrases are very important because the *swara* phrases used in a *Raga Bandish* and the *Raga Vistara* are picked up from all these phrases. Let us assume a set of all these phrases called a set PhrasesAll. Let us assume that U_A and U_D are the set of sequential phrases, let AM_I and AM_{II} be the *Arohi Meend* phrases and DM_I and DM_{II} *Avrohi Meend* phrase and also, we have a set ALM for all the types of *Alamkara* phrases used for ornamentation. Then the set PhrasesAll is the union set of all these sets and represented as follows.

PhrasesAll = $\{U_A \cup U_D \cup AM_I \cup AM_{II} \cup DM_I \cup DM_{II} \cup ALM\}$.

From the set PhrasesAll, it is possible to select specific phrases such as *Graha* phrases, *Nyasa* phrases, *Sama* phrases, *Amsha* phrases etc. that are used in generation of a *Bandish* or required for *Raga Vistara*. Similarly, the phrases that contain *Vadi, Samvadi, Anuvadi, Anu-Anuvadi* etc. *swaras* are also useful for generating a *Bandish*. All such phrases can be chosen from the set PhrasesAll. To simplify the representation, it may be considered that PhrasesAll is a set of phrases useful for *Bandish* generation and *Raga Vistara*. Thus, simplified the representation of PhrasesAll will be as follows.

PhrasesAll = $\{p_1, p_2, p_3 \dots p_n\}$ such that $p_k \in$ PhrasesAll and p_k is useful for a *Bandish* and *Raga Vistara*.

Now it is possible to define various types of phrases that are required for generating a *Bandish* and that are useful for *Raga Vistara*. These phrases are *Graha* phrases, *Nyasa* Phrases, *Sama* phrases and *Amsha swara* phrases. Apart from these phrases *Vadi* phrases, *Samvadi* phrases, *Anuvadi* phrases and *Anu-Anuvadi* phrases are also important. The detailed formal description of a *Bandish* is already discussed in the previous chapter and *Raga Vistara* will be discussed in the next chapter. Let us define these phrases as follows. This description will be useful to define and extend the variables in the formal description of a *Bandish* and the *Raga Vistara*.

Graha Phrases:

As already discussed, that there are specific *swaras* that are considered as *Graha swaras* of the *Raga*. These specific *swaras* are used as a launching pad for a musical phrase or a sequence of a phrases in a composition. Thus, a musical phrase begins on *Graha swaras*. Let us assume a set Graha = {g_1, g_2 ... g_n} that stands as a set of *Graha swaras*. We can assume a set GrahFre = {gp_1, gp_2 ... gp_n} where gp_k PhrasesAll and FIRST-f (gp_k) = f where f ∈ Graha. The function FIRST-f stands for denoting the first member of a phrase.

For example, the set of *Graha swaras* can be Graha = {lni, ni, sa, kga, ga, pa}

The set GrahFre = {[ni, sa, re], [sa, re, ga], [kga, ma, pa], [pa, dha, ni]} you can see that all the phrases in GrahFre are starting from *Graha swaras*.

Nyasa Phrases:

Similarly, as already discussed, that there are specific *swaras* that are considered as *Nyasa swaras* in the *Raga*. *Nyasa swaras* are the *swaras* on which a musical phrase ends or a sequence of a musical phrases end. Let us assume a set Nyasa = {ns_1, ns_2 ... ns_n} that stands as a set of *Nyasa swaras*. We can assume a set NyasaFre = {nsp_1, nsp_2 ... ns_n} where nsp_k PhrasesAll and LAST-l (nsp_k) = l where l ∈ Nyasa. The function LAST-l stands for denoting the last member of a phrase.

For example, the set of *Nyasa swaras* can be Nyasa = {sa, ma, pa}

The set NyasaFre = {[ni, sa], [sa, re, ma], [kga, ma, pa], [pa, dha, pa]} you can see that all the phrases in NyasaFre are ending with the *Nyasa swaras*.

Sama Phrases:

There are specific *swaras* that are considered as *Sama swaras* of the *Raga* which are used at the *Sama* beat of a *Tala*. Let us assume a set Sama = {sms_1, sms_2 ... sms_n} that stands as a set of *Sama swaras*. We can assume a set SamaFre = {$smsp_1$, $smsp_2$ ... $smsp_n$} where $smsp_k$ PhrasesAll and FIRST-f (gp_k) = f where f ∈ Sama. The function FIRST-f stands for denoting the first member of a phrase.

For example, the set of *Sama* swaras can be Sama = {sa, ga, pa}

The set SamaFre = {[sa, ni], [ga, re, ma], [pa, kga, ma], [pa, dha, pa]} you can see that all the phrases in SamaFre have *Sama swara* as the first member. Sama *swara* is always accented in a *Bandish* or in the *Raga Vistara* and coincides with the *Sama* beat.

Amsha **Phrases:**

There are specific *swaras* that are considered as *Amsha swaras* are musically significant and important *swaras* in the *Raga* rendering. Let us assume a set Amsha = {ams_1, ams_2 ... ams_n} that stands as a set of *Amsha swaras*. We can assume a set AmshaFre = {$amsp_1$, $amsp_2$ ... $amsp_n$} where $amsp_k$ PhrasesAll and MEM-m ($amsp_k$) = m where m ∈ Amsha. The function MEM-m stands for denoting a membership.

For example, the set of *Amsha* swaras can be Amsha = {sa, ma, pa}

The set AmshaFre = {[ni, sa], [sa, re, ma], [kga, ma, pa], [pa, dha, pa]} you can see that all the phrases in AmshaFre have *Amsha swara* as a member.

Vadi **Phrases:**

A *Raga* always has a *Vadi swara*. Let us assume a set Vadi = {vadiL, vadiM, vadiH} that stands as a set of *Vadi swaras*. We can assume a set VadiFre = {vp_1, vp_2 ... vp_n} where vp_k PhrasesAll and MEM-m (vp_k) = m where m ∈ Vadi. The function MEM-m stands for denoting a membership.

For example, if the *Vadi* of a *Raga* is Ga then the set of *Vadi swara* can be Vadi = {ga, lga, hga}

The set VadiFre = {[sa, re, ga], [re, ga, re], [lga, lma, lpa], [hsa, hre hga]} you can see that all the phrases in VadiFre have *Vadi swara* as a member.

Samvadi **Phrases:**

A *Raga* always has *Samvadi swaras*- one primary *Samvadi* and the other is called *Anya-Samvadi*. Let us assume a set Samvadi = {samvadiM, anyaM, samvadiL, samvadiH,...} that stands as a set of *Samvadi swaras*. We can assume a set SamvadiFre = {svp_1, svp_2 ... svp_n} where svp_k PhrasesAll and MEM-m (svp_k) = m where m ∈ Samvadi. The function MEM-m stands for denoting a membership.

For example, if the *Samvadis* of a *Raga* are Ga and Re then the set of *Samvadi swaras* can be Samvadi = {ga, re}. This is possible when *Vadi* of the *Raga* is Dha.

The set SamvadiFre = {[sa, re, ga], [re, ga, re], [ga, ma, pa], [pa, re, ma]} you can see that all the phrases in SamvadiFre have one of the *Samvadi swaras* as a member.

Anuvadi Phrases:

A *Raga* always has *Anuvadi swaras*- one primary *Anuvadi* and the other is called secondary *Anuvadi*. Let us assume a set Anuvadi = {panuvadi, sanuvadi} that stands as a set of *Anuvadi swaras*. We can assume a set AnuvadiFre = {avp_1, avp_2 ... avp_n} where avp_k PhrasesAll and MEM-m (avp_k) = m where m ∈ Anuvadi. The function MEM-m stands for denoting a membership.

For example, if the *Anuvadis* of a *Raga* are Dha and Re then the set of *Anuvadi swaras* can be Anuvadi = {dha, re}. This is possible when *Vadi* of the *Raga* is Ma.

The set AnuvadiFre = {[sa, re, ga], [re, ga, re], [ga, ma, dha], [pa, re, ma]} you can see that all the phrases in AnuvadiFre have one of the *Anuvadi swaras* as a member.

Anu-Anuvadi Phrases:

A *Raga* always has *Anu-Anuvadi swaras*- one primary *Anu-Anuvadi* and the other is called secondary *Anu-Anuvadi*. Let us assume a set AnuAnuvadi = {panuanuvadi, sanuanuvadi} that stands as a set of *Anu-Anuvadi swaras*. We can assume a set AnuAnuvadiFre = {$aavp_1$, $aavp_2$ ... $aavp_n$} where $aavp_k$ PhrasesAll and MEM-m ($aavp_k$) = m where m ∈ AnuAnuvadi. The function MEM-m stands for denoting a membership.

For example, if the *Anu-Anuvadis* of a *Raga* are Ma and Re then the set of *Anu-Anuvadi swaras* can be AnuAnuvadi = {ma, re}. This is possible when *Vadi* of the *Raga* is Ga.

The set AnuAnuvadiFre = {[sa, re, ga], [ma, ga, sa], [ga, ma, re], [pa, re, ma]} you can see that all the phrases in AnuAnuvadiFre have one of the *Anu-Anuvadi* swaras as a member.

Emotive Phrases:

There are certain *swaras* that are considered as emotive *swaras*. They bring in emotive flavor while rendering a *Raga*. Typical list of emotive swaras is [CSa, CKRe, KRe, BRe, BGa, KGa, CMa, CMat, CPa, CKDha, KDha, BDha, BNi. KNi]. Let us assume a set EmotiveSwaras = {ems_1, ems_2 ... ems_n} that stands as a set of emotive *swaras*. We can assume a set EmotiveFre = {$emsp_1$, $emsp_2$ ... $emsp_n$}

where $emsp_k$ PhrasesAll and MEM-m ($emsp_k$) = m where m ∈ EmotiveSwaras. The function MEM-m stands for denoting a membership.

For example, the set of emotive *swaras* can be EmotiveSwaras = {kre, kga, mat, kdha, bni}

The set EmotiveFre = {[bni, sa], [sa, kre, ma], [kga, mat, pa], [pa, kdha, pa]} you can see that all the phrases in EmotiveFre have emotive *swara* as a member.

Bhava Phrases:

A set of *Bhava* swara phrases is a union set of the set of *Anuvadi* phrases and the set of emotive phrases. So, the set BhavaFre = {AnuvadiFre ∪ EmotiveFre}.

Sarva Phrases:

A set of *Sarva swara* phrases is made up of *Anuvadi* phrases and the *Anu-Anuvadi* phrases. So, the set SarvaFre = {AnuvadiFre ∪ Anu-AnuvadiFre}. This set has a generic role in the GTIM. While composing a *Bandish* this set provides phrases for various functions. They also act as connector phrases as described in the next paragraph.

Connecter Phrases:

There are various types of connecter phrases that connect two phrases while generating a *Bandish* or while generating a *Vistara* for a *Raga*. The structure of the connecter phrase is such that the first *swara* of the connecter phrase and the last *swara* of the previous phrase are the same. Also, the last *swara* of the connecter phrase is the first *swara* of the next phrase. Thus, the connecter phrase literally connects two phrases. While generating a *Bandish* we need a connecter phrase known as pre-*Sama* phrase. This connecter phrase joins the *Sama* phrase with the previous phrase. Most of the times the previous phrase is a *Sarva* phrase or a *Bhava* phrase or a *Graha* phrase. In the case of *Raga Vistara*, we need a connecter phrase to join the *Sama* phrase with the previous phrase and similarly there needs another connecter phrase that joins the *Nyasa* phrase with its previous phrase. The structure of *Raga Vistara* is discussed in the next chapter.

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CHAPTER 20

Weaving a Melodic Tapestry - *Raga Vistara*

Introduction

With the formal representation of a typical *Bandish* and phrase generation as discussed in previous chapters, it is now evident that most of the concepts can be articulated in a logical and mathematical terms. Many other presentational aspects of Indian music can be articulated in the same fashion based on the formal language thus developed. *Vistara* means elaboration. *Raga Vistara* means elaboration of a *Raga*. A *Bandish* tries to evoke an aesthetic ethos of a *Raga* but it needs to be elaborated further for sustaining the impact. *Vistara* achieves the same. There are various ways to present a *Bandish* or a musical composition in North and South Indian musical styles. There are many genre of musical compositions such as *Dhrupad, Dhamar, Khyal, Thumari, Kajari, Tappa, Hori, Bhajan,* and the light music etc. Some of them are too specific to those styles or *Gharanas.* There exists a great variance in creative expression in terms of presentation. The formal language thus developed in this book is capable of articulating these aspects. For each of the above-mentioned genre there will be a variance of the structure but the formal language will be the same.

The objective of this chapter is to develop a theoretical structure for the elaboration of a *Bandish* of Indian music and articulate it in a formal way. There exists a huge diversity of presentation styles of musical performances as mentioned above. One or two chapters cannot do justice to cover the wide range of presentational aspects of Indian music. The diversity exists in terms of genre, *Gharanas*, vocalists' individual styles, percussion instruments, North Indian and Carnatic styles of music, and diverse contemporary practices of performances. Therefore, the scope of this discussion on *Vistara* of a *Bandish* is delimited to the theory building and the formal representation of Indian music. Focus is not on any specific *Gharana* or style.

A generic model of *Vistara*

A generic model of *Vistara* of a *Bandish* is presented here that captures all the salient features of most of the styles of presentations of North Indian as well as Carnatic music. *Raga Vistara* aims to elaborate on the musical themes of a composition or a *Bandish*. This generic model of *Raga Vistara* takes into account the 'typical' features common to most of the genres. In all the Indian musical performances there is a characteristic pattern of presentation. This pattern has evolved from the *Dhrupad* style. In the North Indian vocal music, it is called '*Badhat*' and has evolved in a particular way that is followed in *Khayal*, *Chhota Khyal, Thumari* and so on. The same *Badhat* pattern has evolved in instrumental music in a slightly different way that has four stages as '*Aalap*', '*Jod*', '*Gat*', and '*Jhala*'. While in the Carnatic music it is called the '*Sopan Marg*' that is climbing a stair case. Normally in the case of *Badhat* pattern, any performance begins in the middle octave or *Madhya Saptaka* and then gradually the exposition of a *Raga* initially settles in the lower octave. Then gradually it proceeds towards the middle octave and then stabilizes in the middle octave. In the later part of the performance the exposition of *Raga Bandish* is taken to the higher octave. Then the performance is concluded either by rendering the original *Bandish* or optionally, the *Raga* is rendered in all the three octaves in a systematic manner. This is just a very broad pattern of the *Raga Vistara* or the elaboration of a *Bandish* as far as the North Indian vocal music is concerned.

Instrumental performances follow slightly different patterns though the elements of *Badhat* are still visible in them. Instrumental music is presented in three/ four stages *Aalap, Jod*, *Gat* and *Jhala*. This pattern has originations in the *Dhrupad* style and therefore, many vocalists also follow this pattern. *Aalap* is an invocation of the mood of the *Raga* without rhythm. No percussion instruments are used during the *Aalap* phase of the performance. It comprises of main phrases of a *Raga*, initially quite simple, with two or three *swaras* nearest to the tonic, and gradually becoming more and more complex extending through the lower and middle *Saptakas* over the whole range of all three *Saptakas*. Meaningful and expressive use of microtones or *Shrutis*, and ornamentations of *Swaras* and *Meends* are the peculiar characteristics of *Aalaps*. A performer attempts to reveal the performer's understanding and sensitivity of the *Raga* through *Aalaps*. *Jod* or *Jor* introduces a rhythmic pulse into the performance again without using any percussion instruments. It begins with short phrases along with regular striking of the drone strings for rhythmic impact. The improvisations become more and more extended, eventually full of rhythmic subtlety and considerable technical virtuosity. *Jod* is a connecting phase between the *Aalap* phase and the forthcoming *Gat* phase. *Gat* is a composition or a *Bandish* composed in a *Tala* having two parts *Sthayi* and *Antara* as been discussed thoroughly in the previous chapters. *Jhala* is a section of the performance where a performer exhibits a variety of virtuosic rhythmic patterns with very fast movements. The *Jhala* can either be the culmination of *Aalap* or *Jod* and/or the climax of the *Gat* part. *Jhala* is the culminating part of the instrumental performance.

From the above description it is clear that whether it is a vocal or instrumental performance, a performer elaborates a musical theme as per once own understanding of the music and the *Raga*. The patterns of *Badhat* or the *Sopan Marga* or the pattern of *Aalap-Jod-Gat-Jhala* provide a broad template for the elaboration of a *Raga*. A performer exhibits once own knowledge, skills and mastery over the voice or over the instrument through *Raga Vistara*. Individual creativity and the mental makeup (*Manodharma*) of the performer play a key role in the *Raga Vistara*.

Role of *Amsha Swara* in *Vistara*

There are certain characteristic features of the *Raga* structure that enhance and facilitate the process of *Raga* elaboration or *Raga Vistara*. Apart from the *Vadi, Samvadi* and *Anuvadi swaras*, one of the important factors in *Raga Vistara* is the *Amsha swara*. *Amsha swara* is also sometimes called *Jeeva swara* or the *Prana swara*. It was mentioned earlier that there are four types of phrases that are important in a *Raga Bandish* as *Vadi* phrase, *Samvadi* phrases, *Anuvadi* phrases and *Anu-Anuvadi* phrases. Similarly in the *Raga Vistara Amsha swara* phrases are very important. First let us try to understand what is an *Amsha swara*. *Natyashastra* has a good deal of discussion on the *Amsha swara* but since the contemporary music is different from the ancient music, we cannot apply the same definition of *Amsha swara* for today's music. We need to reinterpret the traditional definition. With this view an *Amsha swara* can be understood as follows. First of all, there can be multiple *Amsha swaras* for a *Raga*. The candidate *Amsha swaras* can be *Vadi swara, Samvadi swara, Anuvadi swaras, Nitya swaras- Shadja, Panchama,* and *Madhyama*. So, the set of *Amsha swaras* can be defined as follows.

AmshaSwaras = {*Vadi, Samvadi, PAnuvadi, SAnuvadi, Shadja, Panchama, Madhyama*}.

Out of these *swaras*, the *Nitya swaras Shadja, Panchama* and *Madhyama* are the default *Amsha swaras* for the *Raga*. Only when *Madhyama* is a *Vadi* of the *Raga* then *Panchama* cannot be an *Amsha swara* because it is stronger than *Madhyama*. *Vadi* and *Samvadi swaras* are also default *Amsha swaras*. Both the *Anuvadi swaras* can become *Amsha swaras* provided their aural strength is less than the *Vadi swara*. But a very important condition is that the *Amsha swara* should not be an *Ardha-Varjya swara* or it should not be the weak *swara* or the *Durbala swara* in the *Raga*. With these considerations, a set of *Amsha swaras* can be decided to take their *swara* forms from all three octaves. Once this set is finalized then all the *Amsha swaras* need to be arranged sequentially as per their *Saptaka* order starting from the lower octave to the higher octave. For, *Sopan Marga* rendering this order is very important that will be discussed at appropriate place.

Let us take the example of *Raga Bhimapalas* and see what are the possible *Amsha swaras*. In this *Raga Ma* is a *Vadi* and *Sa* is the *Samvadi* along with *KNi* as the *Anya Samvadi swara*. *Sa, Pa*, and *Ma* are the *Nitya swaras*. *Re* and *Dha* are the *Anuvadi swaras*. But *Re* and *Dha* are the *Ardha-Varjya swaras* in this *Raga*. Therefore, *Re* and *Dha* cannot become the *Amsha swaras* in this *Raga*. *Swaras KGa* and *Pa* are the *Anu-Anuvadi swaras*. The *KGa* is any way *Anu-Anuvadi* so it cannot be the *Amsha swara* but *Pa* is a *Nitya swara,* so it is a candidate *Amsha swara*. But since it is aurally stronger than the *Vadi Madhyama*, it cannot be the *Amsha swara* in *Bhimapalas Raga*.

So, the final set of *Amsha swaras* is {*Ma, KNi, Sa*}.

Now by taking the *swara* forms from all three octaves, it becomes {*LMa, Ma, HMa, LKNi*, *KNi, HKNi, LSa, Sa, H Sa, HHSa*}.

After re-sequencing as per the *Saptaka* order the same set will look like as follows- {*LSa, LMa, LKNi, Sa, Ma, KNi, H Sa, HMa, HKNi, HHSa*}.

In the *Raga Vistara* for *Bhimapalas*, these *swaras* are the *Amsha swaras* and their phrases play an important role. In the rendering the *swara* phrases for each *Amsha swara* are constructed and organized in such a way that the *Amsha swara* becomes important. Sometime the *Amsha swara* plays the role of a *Vadi* or the *Graha swara* or the *Nyasa swara* in the rendering. *Amsha swaras* are also made important by repetition. One very important point needs to be kept in mind that there is a lot of variances in presentation styles of *Raga Vistara*. So here an attempt is being made to discuss a generic structure of *Raga Vistara*. Each *Gharana* and each individual performer has one's own way to elaborate a *Raga*. It is not possible to capture all the nuances of *Raga Vistara* in this generic structure. While describing the structure of a *Bandish* in the previous chapter, a special grammar has been developed and a formal language is developed. Continuing the same approach following paragraphs will try to present a grammar and formal language for the *Raga Vistara*. With this understanding of a special grammar for generation of a *Vistara* or the elaboration which is applicable to any *Raga* is developed as follows.

The Generic Grammar of *Vistara*

Here a required terminology from the music domain is used and wherever required the new terminology is introduced. So first let us write down all the rules required for this grammar. They are as follows. The set *Vistara* is as follows. Traditionally, *Vistara* is supposed to be rendered in four stages. In the North Indian music, inherited from the *Dhrupad* style, there are four fixed sections or four parts of *Raga Vistara* of which now-a-days only the first two parts are performed regularly as a *Vistara* of a *Bandish*. The four parts of a *Raga Vistara* are *Sthayi, Antara, Sanchari* and *Abhog*. There is no consensus among the musicians about their exact nature and even about their definitions. This is because, these terms are used to signify musical rendering of a *Raga Vistara* as well as the parts of the lyrical composition. Here we are trying to understand these terms from purely musical point of view.

Accordingly, the first part known as a *Sthayi* or *Astai* is very similar to *Pallavi* of the Carnatic music. The second part is called *Antara* which is very similar to *Anupallavi* of the Carnatic music. The third section called *Sanchari* that is again very similar to *Charanam* in the Carnatic music which is full of *Gamakas* and uses *swaras* from all three octaves. The fourth and concluding section is called *Abhog*. However, contemporary music follows only first two stages- *Sthayi* and *Antara* while the remaining two stages- *Sanchari* and *Abhog* are practiced optionally.

From musical point of view all the traditional four stages are important because a performer can explore wider possibilities of elaboration of a *Raga* through them. Just *Sthayi* and *Antara* are not sufficient. Following discussion is focused on all the four stages thus. As far as the contemporary practice is concerned, the *Sthayi* part of the *Vistara* is rendered in the middle and the lower octave. Performers of different *Gharanas* or even master performers have established their own styles of rendering *Sthayi Raga Vistara* within this range. The *Antara* is mostly rendered in the middle octave and the first part of the higher octave. Again, the individual styles have developed their styles of rendering the *Antara*. *Sanchari* and *Abhog* is not practiced so much now-a-days and therefore it is very difficult to describe the patterns of rendering. *Sanchari* means moving freely or wandering. This third section of a *Raga Vistara* can be rendered using all three *Saptakas.* The performer can exhibit the range of skills including *Gamakas*. The *Abhog* or *Abhogi* is a concluding part of the traditional style of a performance. Contemporary performers conclude their performances sometimes with elaborate '*Tihai*' which may be comparable with the *Abhog*. Thus, *Vistara* of a *Bandish* has four parts that can be represented as below.

<Vistara> → <SthayiVistar> + <AntaraVistar> + <SanchariVistar>

+ <AbhogiVistar>

Normally, the *Dhruvapada* which is the first line of the *Sthayi* part of a *Bandish* is repeated again and again for the impact. First, it is rendered at the beginning of a *Bandish*, and then after the completion of every part of a *Bandish,* it is rendered. A *Dhruvapada* is also known as a *Palupada*. During the *Vistara* also the same pattern continues. *Dhruvapada* is repeated after every *Maha-Avartana* is the chunk of *Vistara Avartanas*. *Avartana* is one cycle of a *Tala*. *Maha-Avartana* is a mega cycle of a *Tala*. It means a set of multiple cycles of a *Tala*. There exists a freedom to the performer to decide the number of lines/ *Avartanas* in the *Vistara Maha- Avartanas*. *Maha-Avartana* is very important in the case of *Vistara* because it is supposed to be the basic unit of *Raga Vistara* in GTIM. Another important aspect of *Maha-Avartana* is that the *Graha swara, Amsha swara, Sama swara* and the *Vinyasa/ Nyasa swaras* are supposed to be fixed for each *Maha-Avartana*. For instance, if a particular *Amsha swara* is chosen then it will be used in all the *Avartanas* belonging to a particular *Maha-Avartana*. One *Maha-Avartana* is separated from the other *Maha-Avartana* by the *Dhruvapada*. *Dhruvapada* is repeated after every *Maha-Avartana*. The celebrated *Badhat* format or the '*Sopan Marga'* format of the *Raga Vistara* proceeds in this manner. This can be briefly explained as follows.

The '*Badhat*' or the '*Sopan Marga*'

In a musical performance, initially, *Dhruvapada* of a *Bandish* is presented followed by the *Sthayi* part followed by the repetitions of *Dhruvapada*. Then the *Antara* is presented followed by the *Dhruvapada* again. This is the way the performer introduces the *Raga* to the audience. Then begins the *Raga Vistara*. *Vistara* also begins with the *Dhruvapada* rendering and then the *Sthayi Vistara* is introduced. For *Raga Vistara* the set of *Amsha swaras* is very important because the *Amsha swaras* are arranged in the hierarchy to manifest the *Badhat* pattern. So, the first member of this set is selected as the first *Amsha swara* during the *Badhat* rendering. Along with that appropriate *Graha swara, Sama swara,* and *Nyasa swaras* are also selected. Now these four types of *swaras* are used for the first *Maha-Avartana*. Once the first *Maha-Avartana* is complete, the *Dhruvapada* is repeated again. Then begins the second *Maha-Avartana*. By following the above- mentioned process, the second *Amsha swara* is chosen from the set of *Amsha swaras* and then other *Graha* etc. *swaras* are chosen for the second *Maha- Avartana*. This process goes on till all the *Amsha swaras* from the set of *Amsha swaras* are exhausted. Since the *Amsha swaras* are arranged from lower octave to the higher octave, the *Amsha swara* chosen for respective *Maha-Avartanas* will be of higher tonality as compared to the *Amsha swara* of the previous *Maha- Avartana*. Therefore, the *Raga Vistara* will proceed from the lower octave to the middle octave and then to the higher octave in a step-by-step manner and therefore this pattern is called '*Badhat*' or the '*Sopan Marga*' (climbing a staircase). This is represented as follows.

<SthayiVistar> → <SthayiVistarMahaAvartana1> +

...<SthayiVistarMahaAvartanaNth>

<AntaraVistar> → <AntaraVistarMahaAvartana1> +

...<AntaraVistarMahaAvartanaNth>

<SanchariVistar> → <SanchariVistarMahaAvartana1> +

...<SanchariVistarMahaAvartanaNth>

<AbhogVistar> → <AbhogVistarMahaAvartana1> +

...<AbhogVistarMahaAvartanaNth>

Let us see the structure of the *Vistara Avartana* within each *Maha-Avartana* to get further clarity. As in the case of a *Bandish* here also there are two parts. The first part is the *Sama* part of the *Vistara* line/ *Avartana* and the other part is the post-*Sama* part of the *Vistara* line/ *Avartana* as shown below.

<SthayiVistarMahaAvartana> → <SthayiVistarAvartana1> +

...<SthayiVistarAvartanaNth>

It means that in each *Maha-Avartana* there can be any number of lines or *Avartanas*. Normally there are two lines in each *Maha-Avartana* but sometimes there can be three, four, five, six or eight lines/ *Avartanas* also. The unit of *Maha-Avartana* is important and the performer has complete freedom to play with or explore with the internal structure of the *Maha-Avartana*. However, normally the *Graha, Amsha, Sama* and *Vinyasa/ Nyasa swaras* are fixed for each *Maha-Avartana*. The structure of each *Avartana* within the *Maha-Avartana* is as follows. Each *Avartana* is divided into two parts as the *Sama* part and the post-*Sama* part as shown below.

<SthayiVistarAvartana> → <SthayiVistarAvartanaSamaPart> +

<SthayiVistarAvartanaPostSamaPart >

The composition of the *Sthayi Vistara Sama* part and the *Sthayi Vistara* post-*Sama* part is described below in a step-by-step manner. First, the *Sama* part description may follow a standard format like the format of the *Avartanas* in a *Bandish.* It looks like as shown below.

<SthayiVistarLineSamaPart> → <SthayiVistarGrahaFre> +

<SthayiVistarGrahaAmshaConnecter> + <SthayiVistarAmshaFre> +

<SthayiVistarPreSamaFre> + <SthayiVistarSamaFre>

Similarly, the post-*Sama* part may also follow the format of the *Avartana* very similar to that is followed in a *Bandish*. It is as follows.

<SthayiVistarLinePostSamaPart> → <SthayiVistarAmshaFre> +

<SthayiVistarPreNyasaFre> + <SthayiVistarNyasaFre>

However, it is not necessary to follow this specific format. A performer can come up with style-specific variations in this format or there can be a completely different format. But assuming that the standard format is followed, then following options open up. Each line/ *Avartana* of the *Sthayi Vistara* is made up of two parts- *Sama* part and the post-*Sama* part. *Sama* part is more critical because it offers multiple possibilities. Five possibilities for the *Sama*-part of the first line of the *Sthayi Vistara* are visualized as follows. These are visualized for the five, four, three, two and one *Tala Khandas* or *Angas* of the pre-*Sama*-part respectively. Same approach is used for the *Bandish* structure. So, there is a consistency in the *Bandish* structure and the *Vistara* structure in this regards. *Sthayi Vistara* can begin even at the partial fractions of *Khandas* or *Angas* but it is not included in the following description currently. If there are more *Tala Khandas* available then the phrase called *Sthayi Vistara Amsha* Phrase will be repeatedly generated as many times as there are extra *Tala Khandas*.

The first phrase is a *Vistara Graha* Phrase. The first *swara* of this phrase is called the *Graha swara* or the starting *swara*. For each *Raga* there is a set of possible *Graha swaras*. This *Graha swara* will be selected from this set. Especially, in this case it will be a set of *Sthayi Graha swaras*. Then the system will search for all the possible phrases that have the *Sthayi Graha swara* as the first *swara*.

The second phrase is required because the *Graha* phrase needs to be connected with the forth coming *Amsha* phrase. This phrase is called *Sthayi Vistara Graha- Amsha* Connecter.

The third phrase is a *Sthayi Vistara Amsha* Phrase. It is called an *Amsha* phrase because the *Amsha swara* for *Sthayi Vistara* is a member of this phrase. So, the system will search for all the possible phrases those have the *Sthayi Vistara Amsha swara* as a member. As already mentioned, there are multiple *Amsha swaras* for the *Vistara*. There exists a set of *Sthayi Amsha swaras* for *Vistara* where all the member *Amsha swaras* are arranged in a sequence. For the first line or the first chunk, to generate the *Amsha* phrases, the first *Amsha swara* from this set is selected and the appropriate *Amsha swara* phrase is selected.

The fourth phrase is called the pre-*Sama* Phrase because it joins the *Amsha swara* phrase to the *Sama swara* Phrase.

The last phrase is called *Sthayi Vistara Sama* Phrase because the first *swara* of this phrase is the *Sama swara*. The *Sama swara* is aligned with the *Sama Khanda* of the *Tala Avartana* or one cycle of a *Tala*. Various possibilities for the *Sama* part are as follows.

Case I for four *Khandas* or *Angas* + *Sam Khanda/ Anga*

<SthayiVistarLineSamaPart> → <SthayiVistarGrahaFre> + <SthayiVistarGrahaAmshaConnecter> + <SthayiVistarAmshaFre> + <SthayiVistarPreSamaFre> + <SthayiVistarSamaFre>

Case II for three *Khandas* or *Angas* + *Sam Khanda/ Anga*

<SthayiVistarLineSamaPart> → <SthayiVistarGrahaFre> + <SthayiVistarAmshaFre> + <SthayiVistarPreSamaFre> + <SthayiVistarSamaFre>

Case III for two *Khandas* or *Angas* + *Sam Khanda/ Anga*

<SthayiVistarLineSamaPart> → <SthayiVistarGrahaFre> + <SthayiVistarAmshaFre> + <SthayiVistarSamaFre>

Case IV for one *Khandas* or *Angas* + *Sam Khanda/ Anga*

<SthayiVistarLineSamaPart> → <SthayiVistarAmshaFre> + <SthayiVistarSamaFre>

Case V for zero *Khandas* or *Angas + Sam Khanda/ Anga*

<SthayiVistarLineSamaPart> → <SthayiVistarSamaFre>

Three possibilities for the post-*Sama*-part of the first line of the *Sthayi Vistara* are as follows. These are designed for the three, two and one *Tala Khandas/ Angas* of the post-*Sama*-part respectively. If there are more *Tala Khandas* available then the phrase called *Sthayi Vistara Amsha* Phrase will be repeated as many times as there are extra *Tala Khandas*. The second phrase is a *Sthayi Vistara* pre-*Nyasa* Phrase. The last phrase is called *Sthayi Vistara Vinyasa* Phrase. When it is a part of the *Dhruvapada* then it is called *Dhruva Nyasa* Phrase. Generally, this phrase is called either *Vinyasa* or *Nyasa* phrase because the last *swara* of this phrase is a resting *swara*. This resting *swara* is chosen from a *Raga* specific set of *Nyasa swaras* and then the system searches for all the possible phrases that have this resting *swara* as the last *swara*. It is important to mention that for the *Sthayi* or even *Antara Vistara* normally, Sa *swara* of the *Madhya Saptaka* is considered as the most suitable *Nyasa swara*. Other *Nyasa swaras* are also can be used but *Madhya* Sa is supposed to be most preferred being the tonic.

Case I for at least two *Khanda* or *Anga + Nyasa/ Vinyasa Khanda/ Anga*

<SthayiVistarLinePostSamaPart> → <SthayiVistarAmshaFre> +
<SthayiVistarPreNyasaFre> + <SthayiVistarNyasaFre>

Case II for one *Khanda* or *Anga + Nyasa/ Vinyasa Khanda/ Anga*

<SthayiVistarLinePostSamaPart> → <SthayiVistarAmshaFre> +
<SthayiVistarNyasaFre>

Case III for at zero *Khanda* or *Anga + Nyasa/ Vinyasa Khanda/ Anga*

<SthayiVistarLinePostSamaPart> → <SthayiVistarNyasaFre>

As shown in the first case above, before the *Vinyasa* phrase there can be any number of *Khandas* available. The last *Khand/ Anga* is reserved for the *Vinyasa/ Nyasa* phrase and the last but one *Khanda/ Anga* (if any) is reserved for the pre-*Nyasa* phrase. The *Amsha* phrase can be used for all the additional *Khandas/ Angas*.

Similar detailing can be worked out for the *Antara Vistara Maha-Avartanas, Sanchari Vistara Maha-Avartanas,* and *Abhogi Vistara Maha-Avartanas* as the standard format. It is not repeated here because the above description is clear enough to get a good idea about the standard format of *Vistara* and the *Vistara* for *Antara, Sanchari* and *Abhog* can be visualized based on this format. However, interestingly in actual performance, the standard format is not followed so strictly or rigorously and it is not mandatory also. Music is a creative domain. The performers are expected to break the rules without sacrificing the aesthetic experience. Performers always try to deviate from the standard norms and therefore, it is not possible to prescribe a specific standard format for the *Raga Vistara*. Thus, here the standard format is described in such a way that it provides a space for the deviation to standard format.

A performer exhibits one's skill and scholarship through *Raga Vistara*. One needs to remember that the role of *Vadi-Samvadi swaras* and *Amsha swaras* is very important in the *Raga Vistara*. Similarly, all types of *Aalaps, Alamkaras* or *swara*-ornamentations, *Gamakas, Meends*, and *Taanas* play very vital role. Display of an instrument-specific peculiarities is also equally important in Raga Vistara. Considering all these factors a performer can plan, design and visualize the strategy for *Raga Vistara*. The core component of the *Raga Vistara* is the *Maha-Avartana* which is made up of number of *Avartanas* and each *Avartana* has *Khandas* or *Angas*. The above-mentioned standard format provides the *Khanda*- level description of *swara* phrases. This is the lowest possible level for the *Raga Vistara* description. To achieve a variation or a deviation from the standard format, one can work out *swara* phrases at one level higher that is the level of *Avartanas*. Each *Avartana* has two parts- *Sama* part and the post-*Sama* part. *Khandas* or *Angas* can be joined together to have larger *swara* phrases, *Aalaps, Taanas* etc. at this level. Even going to further higher level that is the level of *Maha-Avartana* where *swara* phrases, *Aalaps* and *Taanas* can be so large that they can be made up of two *Avartanas* or more *Avartanas*. Especially, for *Sanchari Vistara* where all the three octaves are used, such large *swara* phrases using *Taanas* and *Gamakas* can be explored. Many such possibilities do exist and if one analyses the performances of master performers then it is realized that they have explored these possibilities.

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PART VII
Pulsating Percussions (Ni)

CHAPTER 21

The *Nava Gana Tala* System

Introduction

Any theory of music is incomplete without the discussion of rhythm. Indian system of rhythm is known as the *Tala* system. The word '*Tal*' means to establish or provide foundations. *Tala* provides stability to musical performance- singing, playing instruments, or dance. '*Tal*' also means a palm-stretch. During ancient times clapping and hand gestures were used to indicate the rhythmic cycles and beats. The word *Tala* originated from these hand gestures as well. This is done on the basis of certain rules of temporal measurements. *Tala* is a means or device to measure duration in performing arts in a systematic manner. Performing arts are temporal arts. They exist in time. Any performance is a sequence of activities. In the case of music, it is a sequence of *swaras* organised or designed in a particular order to evoke an aesthetic response from the audience. *Tala* provides a rules- based structure to the sequence/ sequences of *swaras*. In the case of percussion instruments there is an organised sequence of beats. In this sense *Tala* provides temporal foundations to the music.

Rules of *Tala,* thus are based on the units of duration. Traditional units of measuring time duration are '*Kshana*', '*Lava*', '*Kalaa*', '*Truti*', '*Anudruta*', '*Druta*', '*Laghu*', '*Guru*', '*Pluta*', and '*Kakapada*'. The '*Kshana*' is the smallest and shortest unit while the '*Kakapada*' is the largest unit of measuring the duration of time. There are certain specific terms such as '*Laghu*', '*Guru*', and '*Pluta*' which are also used along with the above terms. These terms originate from the *Chhanda Shastra* or an Indian science of prosody. Therefore, there exists a very close association between *Tala* and *Chhanda Shastra*. Theoretically, it can be claimed that *Talas* in Indian music has originated from *Vedic Chhandas* because there exists a close connection between various *Vedic* metres described in *Chhanda Shastra* and the beat patterns of *Talas* used in Indian music [Mainkar, S., 2008, pp. 9-58]. From antiquity to the modern era these concepts are prevalent in Indian music and practitioners have great regard for the same. Apart from the above-mentioned foundational concepts a relatively more systematised paradigm known as the

'*Dasha Pranas* of *Tala*' has been evolved by the tradition. A brief overview of the same is presented below.

Dasha Pranas of *Tala* - Ten Vital Principles of Rhythm

Traditionally, ten vital aspects of *Tala* were considered as the core principles of *Tala* known as *Dasha Pranas*. These are enlisted in all the ancient treatises as *'Kaala', 'Anga', 'Kriya', 'Marga', 'Jati', "Kalaa', 'Graha', 'Laya', 'Yati',* and *'Prastara'. Dasha Pranas* are highly respected by the tradition but among the contemporary scholars there is no consensus about its relevance to today's music. Even there is no consensus about the exact meanings of some of these terms and principles. It may be the case because the North Indian music and the Carnatic music has evolved alternate systems of *Tala* post medieval times such as North Indian *Talas*, *Suladi Sapta Talas* and others like *Chapu Talas*. For instance, it is very difficult to rigorously explain *Trital* in the light of *Dasha Pranas* though *Suladi Sapta Talas* can be related with *Dasha Pranas* to some extent. It appears that there is a need of comprehensive review of the concepts, principles and philosophy of *Dasha Pranas*.

Dasha Pranas of *Tala* in the traditional system articulate various facets of the *Tala* system of rhythm that were prevalent during the ancient era and the medieval era. Contemporary music has changed greatly. GTIM, therefore, tries to re-interpret and re-purpose *Dasha Pranas* with the addition of a few more concepts to the traditional paradigm. In the following passages elements of *Dasha Pranas* are referred to here for inspiration. Some of the terms and nomenclatures are taken from the paradigm of *Dasha Prana* but they are not used in the same sense. GTIM assumes that the 'Time' dimension of *Tala* is very important. Time-oriented analysis of *Tala* helps us in quantifying the concepts in a better way. In the following sections, a great deal of discussion is about the re-phrasing of the fundamental concepts related to *Tala* from a temporal point of view. Similarly, equally important is the psycho-acoustic perspective and related emergent aesthetics of *Tala*. This perspective helps enrich our understanding of *Tala* from a qualitative angle. Going beyond the temporal dimension, this perspective re-interprets many of the foundational concepts of *Tala* by understanding their role in evoking aesthetic response to the *Tala* performance. The temporal perspective contributes to the aesthetic response implicitly while the psycho-acoustic perspective contributes explicitly to the resultant aesthetic response. There is a third section at the end of this chapter where a new system of classification of *Talas* called the '*Nava-Gana*' system is developed that takes into account contemporary North Indian *Talas*, contemporary Carnatic *Talas* and traditional *Talas* including ancient *Talas*. An attempt is made to make the classification system comprehensive, all-encompassing and scalable.

Aesthetics of 'Time' in *Tala*

This section attempts to re-organize the traditional concepts related to *Tala* and the contemporary ideas related to *Tala* in a structured manner. These concepts are first defined and described briefly along with few examples if required. The role of 'Time' or duration is very critical in *Tala.* Therefore, it is necessary to understand the temporal dimension of *Tala* before developing a systematic theory of *Tala*.

Kaala, Marga and Yati: These three concepts from the paradigm of *Dasha Prana* of *Tala* are very important and relevant for contemporary music too. People in general are not aware about these concepts however, while during a performance, knowingly or unknowingly they manifest these concepts in their performance.

Kaala: *Kaala* is the entire time duration used for the musical performance. This should not be confused with the concept of '*Kal*' that will be discussed (in the context of '*Sama*' and '*Kal*') while discussing the structure of an *Aavartana*. A performance can have sub-parts where multiple items are presented one after other. *Kaala* refers to the entire time or duration of all the items put together. It is expected that for the best aesthetic impact, the entire time duration dedicated for the performance should be properly designed. For instance, a performer may present a *Bada Khyal* first and then the *Chhota Khyal* and after that a performer may present a *Thumari* and then a *Bhajan*. *Bada Khyal* may be performed in an *Ekatala* and the *Chhota Khyal* in the *Tritala*. The remaining items may be played in different *Talas* like *Thumari* in *Panjabi Theka* and a *Bhajan* in a *Bhajani Theka*. *Kaala* stands for the duration of all the four items performed and it is expected that a performer has planned every item taking into account the aesthetic impact of each item as well as the overall impact of all the four items.

Marga: *Marga* refers to the way a *Tala* is structured and presented during the performance. It includes style of the performer.

Yati: As per the Indian tradition of *Tala*, the beats of *Tala* need not flow uniformly like a metronome, as it happens in Western music. A performer can take liberty in making variations in the duration of beats as per the need for aesthetic impact. However, this is never done randomly. There are certain patterns in such variations. Duration of beats may be reduced or increased gradually within an *Aavartana* itself. This results into acceleration of the tempo of the *Tala*. The value of beats or *Matras* may be gradually increased or decreased within an *Aavartana* or at the level of *Angas/ Vibhagas*. The tempo of a particular performance can vary at different stages of the performance. For instance, a *Bada Khyal* begins with the *Vilambit* tempo and then gradually enters into the *Madhya Laya* or medium tempo and at the end a *Chhota Khyal* is performed in the faster tempo called *Druta Laya*. This is one well-established pattern of *Yati*. Traditionally, five such patterns were identified as '*Sama*', '*Srotagata*', '*Mridanga*', '*Gopuchchha*', and '*Damaru*'.

With this prelude let us try to define few basic concepts related to *Tala* from temporal perspective. As already mentioned, many of these basic concepts are taken from the paradigm of *Dasha Prana* and many others are quite contemporary concepts.

Some Basic Concepts of Indian Rhythm

Rhythm: In the context of Indian music, rhythm can be defined as a repetition (cyclical) of fixed number of units with variation. This is a broader or generic notion of rhythm that is applicable to temporal arts such as music and dance as well as it can be extended to other art forms.

Tala: *Tala* is the Indian system of rhythm. *Tala* is a rhythmic design of fixed number of beats, with significant arrangement of patterns, to evoke aesthetic response from the audience. More rigorous definition will be provided later on at appropriate place.

Theka: *Theka* is a variation of *Tala*. *Theka* is a characteristic variation of *Bols* adhering to all the rules/features of a particular *Tala*. *Theka* is a concept widely used in North Indian music and many a times confused with the concept of *Tala* itself. Many performers are not able to clearly distinguish between a *Tala* and a *Theka* from theoretical point of view. Carnatic music does not have a concept of a *Theka*.

Kriya: *Kriya* means an action or activity. *Tala* is a device to measure the duration of activities or *Kriya* in a *Tala* performance. Activities involved in a *Tala* are of two types. For instance, the beats are played on the percussion instrument or they are not played but just indicated or counted. When beats are played on the instrument it is called '*Sa-Shabda Kriya'* or the struck sounds. Not playing beats on the percussion instruments does not make any sense. So, certain gestural activities are performed suggesting that there are unstruck beats or there can be a different set of beats that are played softly to indicate the unstruck beats. Such gestures or soft beats are called *'Ni-Shabda Kriya'*. In Indian *Tala* systems, the beats are classified as beats with struck sounds and beats with unstruck sounds or softer beats suggesting the absence of beats. Both types of beats are valid representations for measurement of the duration used in a *Tala*. Metaphorically, *Sa-Shabda Kriya* can be considered as positive space in a painting and the *Ni- Shabda Kriyas* can be equated with negative space in a painting. Both are equally important to counter-balance each other.

Even without the use of percussion instruments *Kriyas* can be denoted by hand gestures. Traditionally, *Tala* is taught and understood in terms of such a set of gestures. Tradition has developed a highly sophisticated system or a codified language of hand gestures to represent *Sa-Shabda Kriyas* and *Ni-Shabda Kriyas*. Contemporary Indian music follows this system very meticulously. In North Indian music the *Sa-Shabda Kriyas* are denoted by a *'Tali'* part of the *Tala* while *Ni- Shabda Kriyas* are denoted by the *'Khali'* part of the *Tala*. The *Tali* is shown with actual clapping while *Khali* is shown with the waving of the hand in North Indian music. Carnatic music has highly sophisticated gestural language for describing '*Kriya*'. *Kriyas* or hand gestures are an important tool of communication between the percussionists and the vocalist or other performers without breaking the flow of counting time in a performance. The major role and significance of hand gestures or these *Kriyas* is to maintain the flow and consistency in counting the *Matras*.

Aavartana: *Avartana* is one cycle of rhythm made up of beats. It has a fixed number of beats.

Matra: *Matra* is considered as the basic unit of a *Tala* which is equivalent to a single beat. The *Avartana* duration of a *Tala* is counted in terms of *Matras* or beats.

Kalaa: *Kalaa* is a minor or fractional unit of the *Matra* (traditionally called *Akshara*) of an *Anga*. It is the minor unit of time by which each *Kriya* is subdivided while representing the *Tala*. In Carnatic music it is also called *Kalai*.

Sama: *Sama* is technically the first *Matra* of the *Aavartana* which is normally accented or stressed. Volume of the *Sama Matra* is always relatively louder than the volume of other *Matras* in an *Aavartana*. Technically, *Avartana* begins with the *Sama Matra* but in an actual performance it may not be the first beat/ *Matra*. However, the performance always concludes on the *Sama Matra*. The term '*Sama*' means equilibrium. *Sama* is a point of aesthetic resolution. Throughout the *Aavartana* a psycho-acoustic rhythmic tension is created by the patterns of *Bols* and beats. At the point of *Sama* this tension is resolved and the audience exclaims the sigh of relief. Performers take liberties in making improvisations at any beat in the *Aavartana* to generate aesthetic tension (at times it happens even across *Aavartanas*) but eventually it is resolved on the *Sama* beat. In this sense *Sama* is a pivotal point in the *Aavartana*. *Sama* is always indicated with the hard stroke/ beat.

Tali: This is a marker to denote the *Sa-Shabda Kriya*. This can come in the beginning of an *Anga*/ *Vibhaga* also. This is very similar to *Sama* but never comes as the first *Matra* of an *Aavartana*. It is less accented and stressed as compared to *Sama*. It is indicated with medium hard strokes/ beats.

Kal: This is a marker to denote the beginning of the *Anga* in an *Aavartana* that has

Ni-Shabda Kriya. This indicates the beginning of the *Ni-Shabda Vibhaga*. This does not have the accent or stress. *Kal* is indicated by soft strokes/ beats.

Khali: This is a general marker to denote the *Ni-Shabda Kriya*. This also does not have accent or stress. *Khali* is always indicated by soft strokes/ beats.

Graha: *Graha* is the beat from which the actual performance begins. The performer has a freedom to begin the performance from any beat of the *Aavartana*. Technically, *Sama* is the first *Matra* of the *Avartana*. *Sama* is highly accented and stressed so it has strong aesthetic impact and the quality of resolving aesthetic tension. To leverage this quality of *Sama,* a performer prefers to start the performance from some other beat, especially, a beat called '*Khali*' or any other softer beats. This beat is called the *Graha* beat. This strategy creates the required aesthetic tension that is resolved at the *Sama* beat. So, *Sama* and *Graha* beats are complementary to each other.

Graha is also the method or a strategy of starting percussion. There are two main types of *Graha* identified. When the percussion and the rest of the music begins at the same time then it is called *'Sama Graha'*. When the percussion and the rest of the music starts at different times then it is called *'Vishama Graha'*. *'Vishama Graha'* opens up two possibilities: if percussion starts after the *Sama* of the *Aavartana* then it is called '*Ateeta Graha'* and if the percussion begins before the *Sama* of the *Aavartana* then it is called *'Anagata Graha'*. These subtilities are very much relevant for contemporary Indian music.

Tempo or *Laya* (and *Layakari*)

Laya: *Laya* is the speed or the tempo of a *Tala*. *Laya* of a *Tala* can be slow, medium or fast. There is a technical terminology used to indicate *Laya*. The slow tempo is called *Vilambit Laya*. There can be an extra-slow tempo which is known as *Ati-Vilambit Laya*. The medium speed is called *Madhya Laya*. The fast tempo is known as the *Druta Laya* and there can be *Ati-Druta Laya* i.e., extra-fast tempo of beats.

Layakari: This is a characteristic phenomenon when beats and *Bols* are played with varied speeds for aesthetic impact while the underlying tempo, such as the metronomic tempo, of the *Tala* is preserved uniformly. The surface level tempo can be of double speed called '*Duggun'*, or triple speed called *'Tiggun'* or there are many variations of speed possible. To achieve these variations, every *Matra* is further split according to the necessary speeds. This variation operates normally at the level of *Aavartana* but there is no strict restriction in this regard. Similar concept is prevalent in Carnatic music. It is called *'Gati'*. The standard *'Gati'* varieties are *Dwyashra* (*Duggun*), *Tryashra* (*Tiggun*), *Chaturashra* (*Chougun* or Quadruple), Khanda (Five times faster), *Mishra* (Seven times faster) and *Sankirna* (Nine times faster). In this case also every *Matra* or a beat is further divided into smaller parts as mentioned here. Following table provides the details of *Gati-Layakari*.

Number of Strokes per *Matra*	**Name of the *Layakari* or *Gati***
1 Stroke per *Matra*	*Ekagun Layakari* or *Barabar Layakari*
5 Strokes over 4 *Matras*	*Kuadi Layakari* or *Savai Layakari*
6 Strokes over 4 *Matras*	*Adee-Deedi Layakari*
7 Strokes over 4 *Matras*	*Biadi- Layakari* or *Paune dugan Layakari*
Double-Time	*Duggun Layakari* or *Dwyashra Gati*
5 strokes over 2 *Matras*	*Mahakuadi Layakari*
6 Strokes over 2 *Matras*	*Tigun Layakari* or *Tryashra Gati*
7 strokes over2 *Matras*	*Mahabiadi Layakari*
4 Strokes per *Matra*	*Chaugun Layakari* or *Chatarshra Gati*
5 Strokes per *Matra*	*Panchgun Layakari* or *Khanda Gati*
6 Strokes per *Matra*	*Chahgun Layakari* or *Maha Tryashra Gati*
7 Strokes per *Matra*	*Satgun Layakari* or *Mishra Gati*
8 Strokes per *Matra*	*Aathgun Layakari* or *Maha Chatarshra Gati*
9 Strokes per *Matra*	*Sankirna Gati*
10 Strokes per *Matra*	*Maha Khanda Gati*
11 Strokes per *Matra*	*Divya Sankirna Gati*

Anga, Pratyangas and *Upangas*

Anga: *Anga* is a chunk of *Matras* or a basic unit of *Tala* made up of a fixed number of *Matras*. The basic structure of a *Tala* is decided by the number of *Anga* units used in the *Tala*. Each *Anga* can have 2 to 10 or 11 *Matras* in it. A *Tala* can have normally two *Anga* units to four *Anga* units but in principle there can be as many *Anga* units as possible. For instance, *Tritala* has four *Anga* units while *Eka Tala* of North Indian style has six *Anga* units. Once all the *Anga* units are completed then that is called one cycle of a *Tala* or one '*Aavartana*' of a *Tala*. In principle there can be any number of *Angas* in a *Tala* but from practical point of view maximum eight *Angas* are manageable. More than eight *Angas* becomes unmanageable. Even keeping track of eight *Angas* becomes quite difficult. Even in the case where *Angas* are made up of a smaller number of *Matras* such as 3 or 4 *Matras* it becomes difficult. Generally, if there are more number of *Matras* in an *Anga* then a smaller number of *Angas* will be better in a *Tala*. During ancient times there used to be big *Talas* having a greater number of *Angas*, even going beyond eight *Angas* but today they are not in practice.

Pratyangas: There is an important concept called *`Pratyanga'*, a sub-division of an *Anga*. An *Anga* can have any number of *Pratyangas*. In a *Chaturashra Jati,* for instance, an *Anga* is made up of 4 *Matras*. It can be divided into two parts. Each part is called a *Pratyanaga*. The four *Matras* can be distributed in two different ways such as 1+3 or 3+1. These different ways are called *Prastara*. These are combinatorial possibilities of dividing the *Anga*. Once any combination is chosen, it is called a *Pratyanga* of the main *Anga*.

Upanga: *Upanga* is an additional small chunk of *Matras* that is added to the *Angas*. In many of the *Sapta Talas* of Carnatic music such as *Dhruva Tala, Matya Tala, Rupaka Tala* or *Jhampa Tala*, along with *Angas* they do have *Upanga*. It is not a mandatory component of a *Tala* in the North Indian *Talas*. However, study of ancient Indian *Talas* show that *Upanga* was very important component of *Talas* in the past, though not mandatory. If the total number of *Matras* is evenly divisible by number of *Angas* then there is no need of an *Upanga* for a *Tala*. However, if the total number of *Matras* are not divisible by the total number of *Angas* in a *Tala* then the remainder as a chunk of *Matras* which is treated as an *Upanga*.

Normally, *Upanga* can have up to 5 *Matras* in it. But if the number of *Matras* in the remainder exceeds 5 *Matras* then the *Upanga* is divided into two parts. Thus, there can be two *Upangas*. The *Upanga*-1 will always have up to 5 *Matras* and the Upanga-2 will have an additional remainder of *Matras*. If there is only one *Upanga* then it is attached at the end of the *Tala*. If there are two *Upangas* then the *Upanga-1*, the larger one is attached at the end of the *Tala* and is placed after the last *Anga* of a *Tala*. If there exists a second *Upanga* then it is placed at the end of the first *Vibhaga* or in other words before the *Kal Vibhaga*. There are three types of *Upangas*. Normally *Upanga* comes at the end of the last *Anga* of the *Tala*. This is called *`Uttara Upanga'* because it comes after the last *Anga*. The second *Upanga* that is placed at the end of the first *Vibhaga* is called *`Aantar Upanga'* because it comes somewhere in between two *Vibhagas* of a *Tala*. Since it is before the *Kal Vibhaga* it plays a role of a prelude to the *Kal* part of a *Tala*. The third type of *Upanga* is called *`Poorva Upanga'* because it comes before the beginning of a *Tala. In that case the Tala* begins with *Upanga*. It plays a role of a prelude to the *Sam Vibhaga* of a *Tala*. In Carnatic *Tala* system there is a *Tala* called *Rupaka*. It begins with *Upanga* followed by the *Anga*. This *Tala* has only one

Anga. Theoretically, there is not much difference between `*Poorva Upanga*' and `*Uttara Upanga'* because they serve the same purpose. *Poorva Upanga* acts as a prelude to the *Tala*, similarly *Uttara Upanga* also acts as a prelude to the next *Aavartana* of a *Tala*. So technically their role is very similar. In some of the textual/ documented references on *Rupaka Tala* of Carnatic system *Poorva Upanga* is shown as *Uttara Upanga*. From this perspective there are only two types of *Upangas*: *Uttara Upanga* and *Aantar Upanga*.

***Anga Prastara*:** *Anga Prastara* is a pattern by which the *Pratyangas* are organized in an *Anga*. As it is defined earlier, *Anga* is a chunk of *Matras*. But if the number of *Matras* in a chunk becomes too larger than it becomes difficult to play such a large chunk of *Matras* in a *Tala* on any percussion instruments. Therefore traditionally, such large chunks are sub-divided into smaller chunks called *Pratyangas* as discussed above. There can be just one *Pratyanga* in an *Anga*. However, in an *Anga* there should not be more than three *Pratyangas*. Even the *Pratyangas* should not have more than four *Matras* in them. There can be various combinatorial ways to make smaller chunks of the *Matras* of an *Anga*. For instance, if there is a chunk of seven *Matras* in an *Anga*, then there can be multiple ways to make smaller chunks like 7= 3+4, 7=4+3, 7=2+3+2 and so many possibilities. That may create quite a chaotic situation. To avoid such a situation the tradition has developed some norms. Firstly, basic unit of any smaller chunk should not be more than 4 *Matras* (as an exception there can be at most 5 *Matras* in a unit in some cases. *Talas* during Vedic times had such chunks.). It means there can be units of 4 *Matras*, 3 *Matras*, 2 *Matras* and 1 *Matra*. Generally, the units of 5 *Matras* and 1 *Matra* are used very rarely. Secondly, in any *Anga Prastara* these smaller chunks should be arranged in an orderly way. The ascending order of smaller chunks is called *Anuloma Krama*, the descending order is called *Viloma Krama*, and finally, there can be an order of smaller chunks that has combination of an ascending order and descending order which is called *Mishra Krama*. The *Sama Prastara* is not acceptable for the *Pratyangas* because they may conflict with the *Angas* of other *Ganas*. For example, in a *Chatarashra Guru Gana* has 8 *Matras* in the *Anga*. It cannot be split as 4+4=8 because it will conflict with the *Chatarshra Gana Talas*. Therefore, *Sama Prastaras* are not allowed for *Pratyangas*. Thus only, *Anuloma Krama, Viloma Krama* and *Mishra Krama* are allowed for *Pratyangas*. Generic *Prastaras* used mostly for the *Nava Gana Tala* system of *Talas* are given below. In the following table, first, the name of a *Prastara* is given. In the second column, in the brackets first number of total *Matras* is given and inside the square brackets the *Matra* divisions of the *Prastara* are given.

Anuloma Prastaras for *Anga* or *Pratyangas*:

Anuloma Krama Prastara	(10, [2, 4, 4]).
Anuloma Krama Prastara	(9, [2, 3, 4]).
Anuloma Krama Prastara	(8, [2, 2, 4]).
Anuloma Krama Prastara	(8, [2, 3, 3]).
Anuloma Krama Prastara	(8, [1, 3, 4]).
Anuloma Krama Prastara	(7, [3, 4]).
Anuloma Krama Prastara	(7, [2, 2, 3]).
Anuloma Krama Prastara	(7, [1, 3, 3]).
Anuloma Krama Prastara	(6, [2, 4]).
Anuloma Krama Prastara	(5, [1, 4]).
Anuloma Krama Prastara	(5, [2, 3]).
Anuloma Krama Prastara	(4, [1, 3]).
Anuloma Krama Prastara	(3, [1, 2]).

Viloma Prastara for *Anga* or *Pratyangas*:

Viloma Krama Prastara	(10, [4, 4, 2]).
Viloma Krama Prastara	(9, [4, 3, 2]).
Viloma Krama Prastara	(8, [4, 2, 2]).
Viloma Krama Prastara	(8, [3, 3, 2]).
Viloma Krama Prastara	(8, [4, 3, 1]).
Viloma Krama Prastara	(7, [4, 3]).
Viloma Krama Prastara	(7, [3, 2, 2]).
Viloma Krama Prastara	(6, [4, 2]).
Viloma Krama Prastara	(5, [4, 1]).
Viloma Krama Prastara	(5, [3, 2]).
Viloma Krama Prastara	(4, [3, 1]).
Viloma Krama Prastara	(3, [2, 1]).
Viloma Krama Prastara	(2, [2]).
Viloma Krama Prastara	(1, [1]).
Viloma Krama Prastara	(0.25, [0.25]).
Viloma Krama Prastara	(0.5, [0.5]).
Viloma Krama Prastara	(0.75, [0.75]).
Viloma Krama Prastara	(0, [0]).

Sarala and *Mishra Prastaras* for *Anga* or *Pratyangas*:

Sarala Krama Prastara	(4, [4]).
Sarala Krama Prastara	(3, [3]).
Sarala Krama Prastara	(2, [2]).
Sarala Krama Prastara	(1, [1]).
Mishra Krama Prastara	(10, [4, 2, 4]).
Mishra Krama Prastara	(7, [2, 3, 2]).
Mishra Krama Prastara	(5, [2, 1, 2]).

Tala Structure: Vibhagas and Angas

The concept of *Vibhaga* is prevalent in North Indian music but in the Carnatic music, it is not found. Ancient systems of *Tala* also do not mention the *Vibhagas* of the *Tala*. So, this concept appears to be a recent one. However, to understand contemporary *Tala* practices, the concept of *Vibhagas* becomes important. In the North Indian system, *Vibhagas* are also called '*Khandas*'. But in GTIM the word *Khanda* is not used to indicate *Vibhagas* because it may confuse with the *Khanda Jati* of the Carnatic *Tala* system. The North Indian *Talas* have much deviated from the *Dasha Prana* paradigm though the terminology used is the same. For instance, it is very difficult to understand the *Tri-Tala* or *Eka-Tala* of the North Indian system from the *Dasha Prana* paradigm. The North Indian system talks about *Vibhagas* and with the *Vibhagas* there are '*Khandas*' or parts which are equivalent to the concept of *Anga* or *Pratyanga* of the ancient system. In any case, it is safer to say that the *Vibhagas* are made up of *Angas*. The following paragraphs attempt to find an agreeable solution for understanding the structure of a *Tala* by defining *Vibhagas* and *Angas* that is relevant to contemporary practices without sacrificing the essence of the traditional paradigm. The GTIM *Tala* description attempts to bridge the gap and provide a comprehensive perspective on contemporary *Talas*.

Vibhaga: A *Tala* may have one, two or three main sections known as *Vibhagas. Vibhaga* is made up of number of *Angas*. Each *Vibhaga* should have at least one *Anga* in it. *Vibhaga* provides a broader structure of the *Tala*. If total number of *Angas* is divisible by two then there can be only two *Vibhagas* in the *Tala* and if it is divisible by three then there can be three *Vibhagas* in the *Tala*. If it is divisible by two as well as three then then there can be two different *Talas* with two and three divisions respectively. If total number of *Angas* is an odd number greater than 3, then *Vibhagas* can have unequal number of *Angas* in them. In such a situation the *Kal Vibhaga* will begin at the (N/2) -1 *Anga* where N is the number of *Angas* in a *Tala*. If there is only one *Vibhaga* in the *Tala* then it is called *Sama Vibhaga*. If there are only two *Vibhagas* in a *Tala* then the first *Vibhaga* is called `Sama

Vibhaga' because it starts with the `*Sam*' part of a *Tala* and the second *Vibhaga* is called `*Kal Vibhaga*' because it begins with `*Kal*' part of a *Tala*. If there are three *Vibhagas* in a *Tala* then the first *Vibhaga* is called the `*Sam Vibhaga*', the second *Vibhaga* is called `*Kal Vibhaga*' and the third and last *Vibhaga* is called a *Mishra Vibhaga* or `*Tali Vibhaga*'. As it is stated each *Vibhaga* should have at least one *Anga* in it. *Upangas* are not part of the *Vibhagas*. *Upanga* is placed at the end of the *Tala* or before the *Kal Vibhaga*. Since total number of *Angas* in a *Tala* does not exceed 8 in general (there were few *Talas* during ancient times having huge number of *Angas*), the number of *Vibhagas* and their component *Angas* are fixed as shown in the following table. This scheme is relevant for traditional as well as contemporary *Talas*.

Number of *Angas*	***Vibhagas***	***Anga* Distribution**	***Sam/Kal/Tali/Khali* Distribution**	***Upanga* 1 Position**	***Upanga* 2 Position**
1	1	1	*Sam*	At the end	Before the *Anga*
2	2	1+1	*Sam+Kal*	At the end	After *Anga* 1
3	3	1+1+1	*Sam+Kal+Tali*	At the end	After *Anga* 1
4	2	1+1+1+1	*Sam+Tali+Kal+Tali*	At the end	After *Anga* 2
5	2	[1+1] + [1+1+1]	*Sam+Tali+Kal+Khali+Tali*	At the end	After *Anga*2
6	3	[1+1] + [1+1] + [1+1]	*Sam+Tali+Kal+Khali+Tali+Tali*	At the end	After *Anga* 2
6	2	[1+1+1] + [1+1+1]	*Sam+Tali+Tali+Kal+Khali+Tali*	At the end	After *Anga* 3
7	3	[1+1] + [1+1] + [1+1+1]	*Sam+Tali+Kal+Khali+Tali+Tali+Tali*	At the end	After *Anga* 2
7	2	[1+1+1] + [1+1+1+1]	*Sam+Tali+Tali+Kal+Khali+Tali+Tali*	At the end	After *Anga* 3
8	2	[1+1+1+1] + [1+1+1+1]	*Sam+Tali+Tali+Tali+Kal+Khali+Tali+Tali*	At the end	After *Anga* 4

Generative Role of *Vibhagas*:

Vibhagas provide a broader structure and rhythmic foundations to the *Tala*. A Tala is divided into two or three *Vibhagas*. The first *Vibhagas* in a *Tala* is called the `*Sam Vibhaga*' that plays a generative role. The *Sam Vibhaga* acts as a catch theme or signature theme of a *Tala*. It defines the rhythmic structure and pattern of a *Tala*. Number of *Matras*, their *Prastara* structure, types of *Talas Bols* and number of

Angas and/ or *Pratyangas* are defined in the *Sam Vibhaga*. Thus, the first *Vibhaga* or the *Sam Vibhaga* defines the natural rhythmic aesthetics of a *Tala*. The same structure is replicated in the *Kal Vibhaga* with one change. Only *Tala Bols* are changed. *Kal Vibhaga* acts as a negative space thus generating balance between the *Sam Vibhaga* and the *Kal Vibhaga*. *Sam Vibhaga* is made up of `*Bhari*' *Bols* while the *Kal Vibhaga* is made up of their equivalent counter parts called `*Khali*' *Bols*. (More elaborate discussion of *Bhari* and *Khali Bols* is done in following sections of this book.) If there are three *Vibhagas* in a *Tala* then the third and the last *Vibhaga* is called *Tali Vibhaga* or the *Mishra Vibhaga* and follows the same structure and *Prastara* pattern as that of the *Sam Vibhaga* with minor changes. As stated, the *Sam Vibhaga* is like a positive space and the *Kal Vibhaga* is like a negative space while the *Tali Vibhaga* is like mixed space. All the *Bols* of *Tali Vibhaga* are same as that of the *Sam Vibhaga Bols* except one change. One or two *Bhari Bols* of *Tali Vibhaga* are changed into *Khali Bols* following certain rule. One *Maha Prana Guru Bol* is changed to *Alpa Prana Guru Bol* and if there are consecutive *Maha Prana Madhya Bol* then the second one is changed into *Maha Prana Guru Bol*. This sounds very complex but this brings in a beautiful rhythmic pattern. Apart from that, if there are more than one *Angas* in the *Tali Vibhaga* then the order of these *Angas* is reversed adding more complex aesthetics. However, in this reversal process, only the order of *Angas* is reversed while the order of inner *Pratyangas* and *Matra Prastara* is not reversed. It is preserved. Let us take the example of *Eka Tala* of North Indian music. It is made up of 12 *Matras* and has three *Vibhagas*. It is *Chatarashra Gana/ Jati* with two *Pratyangas* in each *Anga*. It is written as follows.

Eka Tala = [

[[[sam], [Dhin, Dhin]], [[tali], [Dhagi, Tirkit]]], ...*Sam Vibhaga*

[[[kal], [Tu, Na]], [[khali], [Kat, Ta]]], ... *Kal Vibhaga*

(Technically this can be [[[kal], [Tin, Tin]], [[khali], [Tagi, Tirkit]]]),

[[[tali], [Dhagi, Tirkit]], [[tali], [Dhin, Dhin]]], ... *Mishra/ Tali Vibhaga*

].

In this case, the *Sam Vibhaga* has an *Anga* with two *Pratyangas* as [[sam], [Dhin, Dhin]], and the other *Pratyanga* is the [[tali], [Dhagi, Tirkit]]. In the last *Vibhaga* which is a *Mishra Vibhaga* the same *Anga* is preserved but the sequence of *Pratyangas* is changed. The first *Pratyanga* is made the second and the second *Pratyanga* is made the first in the last *Vibhaga*. This reversal of the sequence of *Pratyangas* in the *Mishra Vibhaga* produces interesting aesthetics of rhythm. Interestingly, although the sequence of *Pratyangas* is reversed the internal structure of each *Pratyanga* is kept intact. The internal structure of each *Pratyanga* is not reversed.

The temporal characterization of a Tala is complete here.

Psycho-Acoustic Aesthetics of *Tala*

In the earlier sections of this chapter, the whole discussion has been revolving around the temporal aspect of a *Tala*. *Tala Avartanas*, *Angas, Pratyangas*, their *Prastaras* and *Matras* or beats are understood in terms of their temporal dimension. *Tala* divides the time duration of performance in characteristic ways. *Matra* is the basic unit of this measurement. The discussion also touched upon the concepts of *Sa-Shabda Kriya* and *Ni-Shabda Kriya* which indicated other dimensions of *Tala* that go beyond the temporal realm. In the following sections of this chapter, an attempt is made to elaborate on these other aspects of *Tala* that go beyond the temporal dimension.

Tala Bols

As we know *Talas* are played on percussion instruments like *Mridangam* or *Tabla* etc. The sounds of these instruments are produced through characteristic strokes having peculiar sonic qualities. To represent these sounds of the strokes, certain syllables or *Aksharas* are used to denote them traditionally. For representing *Mridangam* sounds syllables like Tita, Ta, Kita etc. are used. Similarly for denoting *Tabla* sounds syllables like Dha, Dhin, Dhi, Ta etc. are used. These syllables are used to represent the sounds of that particular instrument. In this sense, these syllables are highly instrument-specific. There is no scheme of the instrument-independent syllables to denote sounds which can explain the structure of a *Tala*. However, there is a need for the formalization of such sounds that may be defined as '*Tala Bols*'. The term '*Bol'* literally means sounds or syllables produced by humans. To arrive at an instrument-independent scheme of sound representation one needs to understand the generic nature and structure of sounds that comprise a *Tala*. *Tala Bols* are acoustically and aesthetically loaded beats. *Sa-Shabda Bols* are strong strokes of the beats while the *Ni-Shabda Bols* are indicated by softer strokes. At such a generic abstract level, All the sounds used for *Tala* representing a *Tala* can be categorized into five types *Guru Bols, Laghu Bols, Ardha Bols, Madhya Bols* and *Avagraha.*

Laghu Bol is a soft syllable produced for one *Matra* duration like 'A'.

Guru Bol is a strong syllable produced for one *Matra* duration like 'Aa'.

Ardha Bol is a consonant sound produced for one *Matra* duration. It generates the sound effect of `stop' or breaking the flow of pronunciation.

Madhya Bol is a middle state of *Laghu Bol* and the *Guru Bol* that produces the sound effect that is not very soft and not very strong.

The *Avagraha Bol* is an absence of producing sound that means absence of sound for one *Matra* duration. Practically it so happens that since there is an absence of any sound, the impact of sound produced by the previous syllable gets extended.

There is one more possibility of representing a conjunct *Tabla Bol* such as '*KDan*' or '*KDon*' where more than one syllables are used that may involve combinations of consonants, vowels, conjuncts pronounced at the same time. Such *Bols* are not considered as basic *Bols*. Thus, there can be five types of representations for *Tala Bols* as *Guru Bols, Laghu Bols, Madhya Bols, Ardha Bols,* and *Avagraha.* Throughout this book these *Tala Bols* will be represented by standard *Tabla* sounds for the sake of simplicity of understanding.

Guru Bol will be represented by either 'Dha' or 'Ta'.

Laghu Bol will be represented by 'Dhi' or 'Ti'.

The *Ardha Bol* will be represented by 'k' or 'ak' to suggest the sound effect of 'stop'.

Madhya Bol will be represented by the *Tabla Bol* sound 'Dhin' or 'Tin'.

The *Avagraha* will be represented as *Avagraha*, a special sign for Avagraha as "..." or by a letter 'S'.

These conventions are useful because currently *Tabla* sounds are quite popular and the expected *Tala* sounds can be articulated in a best possible way. There is another reason to choose these specific *Tabla* sounds because they help in expressing few other properties of *Tala Bols* sounds. It is repeatedly being said that these are abstract representations of beats or strokes because the sounds that all the percussion instruments produce are not capturable by human language. At some abstract level we need to find salient qualities and sonic properties of *Tala* instrument sounds and articulate them through proper language. When *Tala* instruments are played it is not only the case that the sounds produced adhere to time durations alone. These sounds have other sonic qualities such as loudness, timbre, tonality, accent, resonance and many other stylistic properties that contribute to the impact of the rhythm. When all these properties are taken into consideration it becomes even more challenging to represent them by using human language. However, at some abstract level we can imagine and understand them by using the above-mentioned scheme. In this sense this is an instrument-neutral scheme.

In *Mridangam* or *Tabla,* certain sounds are produced using both sides of *Mridangam*. In the case of *Tabla,* certain sounds are produced on both the units of *Tabla* called `*Daya*' and '*Baya*'. Such sounds need more effort to produce as well as generate more resonating sounds. Traditionally all such sounds are called

`Bhari' Bol* and used in the *`Sam' part of a *Tala*. Technically they are called *`Maha Prana' Bols*. In the above scheme `Dha', `Dhin' and `Dhi' stand for the *Maha Prana Bols* or *Bhari Bol*s.

There are other types of sounds that are produced on any one side of the *Mridangam* or on any one part of the *Tabla*. All such sounds require less efforts to produce and they produce less resonating impact. Such sounds are called *`Alpa Prana' Bols* or *`Khali' Bols*. In the above scheme `Ta', `Tin', `Ti' stand for *Khali Bols* and traditionally used in the *`Kal*' part of the *Tala*.

Thus, usually first *Vibhaga* of a *Tala* which is a *Sam Vibhaga* will always have the *Maha Prana Bols* or *Bhari Bols* while the second *Vibhaga* of a *Tala* which is always a *Kal Vibhaga* will have *Alpa Prana Bols or Khali Bols*. If there exists the third *Vibhaga* then it will have both the types of *Bols: Bhari Bols* as well as *Khali Bols*. In this *Vibhaga* all the `Dha' *Bols* will be replaced by `Ta' and rest of the *Bols* will remain same as that of the *Sam Vibhaga*. This smaller change brings in a major impact because `Dha' is a very strong *Maha Prana Bol*. By converting *Maha Prana* `Dha' into an *Alpa Prana* `Ta' *Bol,* overall impact of third *Vibhaga* is toned down. This is necessary for aesthetic requirement of *Tala* Logic.

Traditionally, the impact of *Maha Prana Bols* and *Alpa Prana Bols* is termed as relative *`Vajan*' or weight of the *Bols*. The *Maha Prana Bols* create more *Vajan* (weight) while *Alpa Prana Bols* create less *Vajan* (weight). For generating appropriate *Tala* aesthetic impact there should be an appropriate rhythmic balance between the *Sam Vibhaga* and the *Kal Vibhaga* of a *Tala*. If there exists a third *Tali Vibhaga* then it should have mixed *Vajan Bols* to balance the rhythmic flow. This is further elaborated in following paragraphs.

Vajan or the Aesthetics of Relative Weight of the *Bols*

Every *Bol* stands for one *Matra*. That means each *Bol* is to be played for one unit of duration. If the *Bol* that is played is *Maha Prana Bol,* then it will have more resonance and impact. If the *Bol* is the first *Bol* of the *Anga,* then being the first *Bol,* it will get maximum stress as well. Due to such factors, the overall impact of the *Bol* will be maximum. This overall impact of a *Bol* is called the *`Vajan*' or a relative aesthetic `Weight' of the *Bol*. Thus, the *Vajan* or weight of a *Bol* depends upon whether it is *Laghu* or *Guru*, whether it is *Alpa Prana* or *Maha Prana*, where it is positioned in the *Anga* or its *Pratyanga*, whether it is followed by *Avagraha* or not, whether it is followed by *Ardha Bol* or not, whether it is played loudly or not and enough resonance and stress is given or not. Due to such factors, the *Vajan* of a *Bol* will vary though the *Bol* is played for one *Matra*. To capture this phenomenon a generic scheme is developed where *Dha* represents a maximum weight while *Avagraha* represents minimum weight.

The generic order of the relative weight of the *Bol* will be as follows:

Dha > Dhin > Dhi > Ta > Tin > Ti > *Ardha* > *Avagraha*.

The left-most Dha has the maximum weight while the right-most *Avagraha* has minimum weight in the above representation.

In any given *Anga* or *Pratyanga* when *Bols* are arranged they will carry *Vajan* or weight with them and because of that *Tala* patterns will generate aesthetic patterns. It is possible to devise generic scheme of rules of these aesthetic patterns.

All the *Tala Bols* follows certain rules.

- Any first *Anga* of a *Tala* which is also called the signature *Anga* of a *Tala* should begin with *Guru Bol* or *Madhya Bol* that is either with Dha, Dhin or Dhi only and not by any other *Vajan Bol*.
- Any first *Anga* can start with a *Laghu Bol* Dhi but in that case generally Dha should not be a part of the *Anga*. Dhin *Bol* may follow Dhi *Bol* but this condition is not very strict.
- Any first *Anga* of a *Tala* which is also called the signature *Anga* of a *Tala* should never start with *Avagraha* or *Ardha Vajan Bols*. Traditionally, there are so called *Talas* which start with *Avagraha* but these are the *Thekas* and not the *Talas*.

These are the structural rules for generating the original new *Tala* and therefore these rules need not be followed for *Theka* generation or for the generation of any other variations on the *Tala* while rendering a *Tala* performance.

Categories of *Tala Bols* based on *Vajan*

Based on the above-mentioned rules eight categories of *Tala Bols* are possible. These possible categories are briefly discussed below. *Anga* can have just one *Pratyanga* or there can be more than one *Pratyangas*. Normally there can be at most three *Pratyangas* in an *Anga* because an *Anga* of ten or even fifteen *Matras* can be divided into three *Pratyangas*. Maximum length of a Pratyanga can be four *Matras* and very rarely five *Matras*. Each *Pratyanga* is made up of *Tala Bols* made up of *Guru Bol, Madhya, Laghu, Ardha,* or *Avagraha*.

Each *Tala Bol* has rhythmic impact and accent due to their inherent structure. Combinations of *Tala Bols* in an *Anga* generate collective impact which can be called the *Vajan* of the *Anga*.

Avagraha brings in a kind of openness in the *Anga* or *Pratyanga*. *Ardha* creates an effect of `stop’ in the overall *Vajan* of an *Anga*. *Madhya* causes a medium `stop’ impact.

If there are two or more number of *Avagrahas* then then there will be more `open' *Vajan*. If there are two or more *Ardha Bols* then the *Vajan* will be more closed and `stop'. If *Avagraha* and *Ardha* both are present in the *Anga* then the *Vajan* impact will be mixed or `*Mishra*'. Similarly, if in any *Anga* there is an absence of *Avagraha, Ardha* and *Madhya* then the *Vajan* impact of the *Anga* will be without any special effect or accent. Such an *Anga* may be defined as without any impact or `*Anaghata*'. There exists a kind of hierarchy in the *Vajan* impact of each *Bol*. This is a hierarchy in terms of the '*Vajan*' impact caused by accent and such other factors of *Bols*. It is not the hierarchy of the strength of *Bols*.

Vajan impact of *Avagraha* is maximum due to openness that overpowers the impact of another *Bols* except *Ardha*.

The impact of *Ardha* comes second and overpowers another *Bols* except the *Avagraha*. That is why *Avagraha* and *Ardha* will create a mixed impact or *Mishra Vajan* impact.

The impact of *Madhya Bol* comes third. It overpowers other *Bols* but is suppressed by *Avagraha and Ardha*.

Guru Bol is stronger than the *Laghu* but is over powered by rest of the *Bols*. *Laghu* has minimal impact in terms of *Vajan* of an *Anga*.

Thus, looking at all such possibilities *Angas* or *Pratyangas* can be defined in a following way.

1. If there exists *Avagraha* and *Ardha* both in the *Anga* then that *Anga* may be termed as having mixed or *Mishra Vajan*.
2. If there exists two or more *Avagrahas* in an *Anga* than that *Anga* may be termed as *Avagraha-Bahul Anga*.
3. If there exists two or more *Ardha Bols* then the *Anga* is *Ardha-Bahul*.
4. If there is only one *Avagraha* and no *Ardha* or no *Madhya* then it is *Sa-Avagraha Anga*.
5. If there is only one *Ardha* and no *Avagraha* or no *Madhya* then it is *Sa-Ardha Anga*.
6. If there is at least one *Madhya* and no *Ardha* or no *Avagraha* then it *Sa-Madhya Anga*.
7. If there is at least one *Gurvardha* and no *Ardha* or no *Avagraha* then it *Sa-Gurvardha Anga.*
8. If in any *Anga* there is an absence of all three- *Ardha, Avagraha* and *Madhya*, then such an *Anga* is *Anaghata Anga*.

Thus, *Angas* or *Pratyangas* can be categorised in these eight categories to understand the *Vajan* of an *Anga*. When *Angas* have only one *Pratyanga*, it is easy to categories the *Anga*. But if there are more *Pratyangas* in an *Anga* then each *Pratyanga* will have *Vajan*. To avoid such a complication, *Vajan* of an *Anga* can be decided by putting all the *Pratyanga Bols* together and then deciding the overall *Vajan* of an *Anga*. Once the *Vajan* or the relative aesthetic 'Weight' of the signature *Anga* is decided, the *Vajan* of all the other *Angas* will appropriately fall in line. *Maha Prana Bols* used in the *Sam* and *Tali* parts and the *Alpa Prana Bols* used in the *Kal* and/ or *Khali* parts will also create relative *Vajan* impact as per their respective properties. The *Maha Prana Bols* will have more *Vajan* impact than the *Alpa Prana Bols*. The overall *Vajan* of a *Tala* is decided by these factors but the signature *Anga* plays the seminal role in this process.

Weight or *Vajan* of a *Tala* is a unique Indian concept. It refers to the cumulative impact of *Bols* in the *Anga* or *Pratyangas* created due to accent, stop, extension of a *Bol* or the absence of a *Bol*, a simple stroke of the beat and a simple stroke added with stop effect. As already mentioned, there are *Guru Bols, Laghu Bols, Madhya Bols*, stop and *Avagraha* as *Bols*. *Guru Bols* such as *Dha* are most of the time responsible for the impact of accent and strength. *Laghu Bols* such as *Dhi* produce simple soft stroke effect. *Madhya Bols* such as *Dhin* produces accented soft effect while k produces the stop effect and *Avagraha* stands for the absence of a *Bol* but it causes the extension of the previous *Bol* if any. Due to these properties of the *Tala Bols* when they are organized in an *Anga* or *Pratyanga* they result into complex impact. Cumulatively this impact is called the weight or the *Vajan* of an *Anga* or the *Pratyanga*.

When the counterparts of the above-mentioned *Tala Bols* such as *Ta* for *Dha*, *Tin* for *Dhin* and *Ti* for *Dhi* are used in the *Khali Angas* or *Kal Angas* or *Pratyangas* then they produce non-accented impact. The *Bhari* part of the *Tala* has the positive accented impact while the *Khali* or *Kal* part of the *Tala* has the negative non-accented impact. Collective impact of the *Bhari* part and the *Khali* part decides the overall weight or *Vajan* of the *Tala*. Weigh of the *Tala* is experienced and felt during the *Tala* performance and can be very broadly understood in the following manner.

For instance, if the *Anga* or *Pratyanga* made up of four *Matras* as [*Dha, Dhin, Dhin, Dha*] then the weight or *Vajan* can be understood as follows. This example has at least two *Guru Bols* with first *Guru Bol* and therefore, total dominance of *Guru Bol* will be experienced. There are two *Madhya Bos* as well but since *Guru Bol* holds the first position in an *Anga* or *Pratyanga* it is dominated by *Guru Bol*. If we make a small change in the above example as [*Dha, Dhin, Avagraha, Dha*] then additionally, this *Anga* or *Pratyanga* also have an *Avagraha* as a member so it brings in a special flavour to the *Vajan*. Therefore, this *Anga* may be termed as *Sa-Avagraha Guru Angas*. But in this case instead of *Avagraha* if we put 'k' or the stop as an *Ardha Bol* that will change the overall flavour of the *Vajan* of the *Anga* or a *Pratyanga*. *Ardha Bol* brings in the effect like a stop or a pause or a break that brings in the special flavour. It will look like [*Dha, Dhin, k, Dha*] and can be understood as *Sa-Ardha Guru Anga* or *Pratyanga.*

If we take another example as [*Dhin, Dhin, Dha, Dhin*] then it will have a completely different flavour. In this example, *Madhya Bol* is holding the first position and will have more emphasis in terms of *Vajan. Madhya Bol* has one more advantage. It has the effect of stopping or pausing in-built in it. That's why the *Vajan* flavour of *Guru Bol* and the *Vajan* flavour of *Madhya Bol* is different and comparable in some sense. Still, *Guru Bol* is considered stronger than *Madhya Bol* given that all the other parameters are the same. If we replace the second *Bol* with k then it will have *Sa-Ardha Madhya* weight or *Vajan*. It will look like [*Dhin, k, Dha, Dhin*] and the *Bol* k or *Ardha*/ stop impact brings in a very interesting impact. If k is replaced with *Avagraha* then it becomes [*Dhin, Avagraha, Dha, Dhin*] and causes the extension of the *Dhin* sound bringing in the *SaAvagraha Madhya* effect. These examples have clear dominance of *Madhya* impact since there are two *Madhya Bols* and one of them is holding the first position. It has positional advantage. Secondly these *Angas* or *Pratyangas* have only one *Guru Bol* so naturally it will have less impact. Many such examples are possible for smaller *Angas* or P*ratyangas* with four, three, two and one *Matras*. The above description of *Vajan* is indicative of the flavours of *Vajan*. There are many more experiential qualities of the concept of *Vajan* that are not very easy to capture in words.

Computing *Tala Bol Prastaras* for *Angas* and *Pratyangas*

Following are typical examples of *Angas* or *Pratyangas* with specific number of *Matras* and relevant *Vajan Bols*. In following example very few select cases are shown. This is not an exhaustive list of possibilities of *Angas* or *Pratyangas*. The signature *Anga* decides the structure and the weight of the *Tala*. It can be made up of just one single *Anga* or it can have *Pratyangas* within it. For the clarity of the role of *Pratyangas* within the *Anga* two groups of all the possible *Pratyangas* are formed. The first group of *Pratyangas* comprises of *Pratyangas* that come as the first *Pratyanga* in a signature *Anga* or any other *Anga* for that matter. Let us call such *Pratyangas* as '*Sam Pratyangas*'. There are other types of *Pratyangas* that come next to the first *Pratyanga* or the *Sam Pratyanga*. Such *Pratyangas* can be called 'General *Pratyangas*'. All general *Pratyangas* form the second group. As a rule, the first *Bol* of the first *Pratyanga* can be either *Dha, Dhin,* or *Dhi*. That is because these *Bols* bring in the required accent to the *Sama Bol* or the first *Bol* of the first *Pratyanga*. Rest of the *Pratyangas* do not have this requirement of accent. Rest of the *Pratyangas* can begin with any of the five *Bols* as -*Dha, Dhin, Dhi, k, Avagrah]*.

Thus, *Anga* is made up of one *Pratyanga* or multiple *Pratyangas*. Sometimes it becomes very difficult to distinguish between consecutive *Pratyangas* if there is more than one *Pratyangas* in the *Anga*. To resolve such confusion a norm is needed. It can be a good norm to use the neutral *Bol* as a first *Bol* of the second or third *Pratyangas* to sort out any confusion. For instance, if there is an *Anga* with two *Pratyangas* as [[*Dha, Dhin*], [*Dha, Dhin, k*]]. In this *Anga* there are two *Pratyangas* as [*Dha, Dhin*] and [*Dha, Dhin, k*]. When these two *Pratyangas* are played in a sequence it may be difficult to find out where the first *Pratyanga* ends and from where the second *Pratyanga* begins. To avoid such confusion there should be a way to distinguish between two consecutive *Pratyangas*. To resolve this issue two norms are developed. These norms are embedded in the tradition implicitly. However, they are articulated explicitly here in GTIM. The first norm is that the first *Bol* of the second *Pratyanga* can be a neutral *Bol* such as *Na, Tita, Kita, Tiri*, or even *Tirikit* etc. Accordingly, now the *Anga* and *Pratyangas* in the above example will look as follows [[*Dha, Dhin*], [*Na, Dhin, k*]] or [[*Dha, Dhin*], [*Tirikit, Dhin, k*]]. If this happens to be a signature *Anga* then the *Kal Anga* for it will look like this [[*Ta, Tin*], [*Na, Tin, k*]] or [[*Ta, Tin*], [*Tirikit, Tin, k*]]. Thus, this norm of using neutral *Bol* as the first *Bol* of the second or third *Pratyanga* in the *Anga* is very useful to resolve any confusion.

The tradition has also developed another norm to resolve this issue. It is done by putting either a *Tali* or a *Khali* before every *Pratyanga* depending on whether it is in the *Bhari* part of the *Tala* or the *Khali* part of the *Tala*. Accordingly, now the *Anga* and *Pratyangas* in the above example will look as follows [[*sam*], [*Dha, Dhin*], [*tali*], [*Dha, Dhin, k*]]. If this happens to be a signature *Anga* then the *Kal Anga* for it will look like this [[*kal*], [*Ta, Tin*], [[*khali*], [*Na, Tin, k*]]. In contemporary *Talas*, generally there are no more than three *Pratyangas* in an *Anga*. If there are more *Pratyangas* in the *Anga* then still the same norm works well. Above-mentioned both the norms are very important and we can find ample examples of both the norms in the tradition. Even there are few instances where both these norms are combined that means for each *Pratyanga* neutral *Bols* are used as the first *Bol* of a *Pratyanga* and/ or *Pratyangas* are separated by *Tali* or *Khali*.

It is a very good computational exercise to compute the possibilities of generating *Angas* or *Pratyangas* made up of one *Matra*, two *Matras*, three *Matras* and four *Matras* and even for five *Matras*. There is one important condition that same *Bol* should not be repeated thrice consecutively. For instance [*Dha, Dha, Dha*] cannot be a valid *Pratyanga* for three *Matras*. This rule is also applicable for consecutive *Pratyangas* so [*Dha, Dha*] followed by [*Dha, Dhin*] is also not valid. With this understanding number of possible *Pratyangas* can be worked out based on the conditions enlisted as follows.

The basic set of given *Bol* is = {*Dha, Dhin, Dhi, k, Avagraha*}.

Condition No. 1: k and *Avagraha* cannot be the first *Bol* of a *Sam Pratyanga*. They can be the first *Bols* of general *Pratyangas*.

Condition No. 2: A *Bol* cannot be repeated thrice consecutively in a *Pratyanga* or in an *Anga*. A *Bol* can be repeated as [*Dha, Dha*] or [*Dha, Dhin, Dha*] or even [*Dha, Dhin, Dha, Dha*]. In the last case the *Bol Dha* comes three time in the *Pratyanga* of four *Matras* which is allowed because it is not repeated thrice in a row but [*Dha, Dha, Dha, Dhin*] is not allowed because here the *Bol Dha* is repeated thrice in a row.

Condition No. 3: The *Bols* k and *Avagraha* cannot be repeated consecutively as [*k, k, Dha*] or [*Dha, k, k*] but they can be used twice in longer *Pratyangas* like [*Dha, k, Dhin, k*].

The above conditions are limited to the usage of *Bols* for generating a signature *Anga* or *Pratyangas*. These conditions are not applicable to general rendering of *Bols* in a performance. Following possibilities of the permutations of *Bols* from the above set are worked out as follows.

For an *Anga* or *Pratyanga* of One *Matra*:

Sama *Pratyangas* for single Matra: [*Dha*], [*Dhin*], [*Dhi*] three possibilities as *k* and *Avagraha* cannot be the initial *Bols* in *Sam Pratyangas*.

General *Pratyangas* for single *Matra*: [*Dha*], [*Dhin*], [*Dhi*], [*k*], [*Avagraha*] as five possibilities.

For an *Anga* or *Pratyanga* of Two *Matras*:

Sama Pratyangas for two *Matras*:

[Dha, Dhin], [Dha, Dhi], [Dha, k], [Dha, Avagraha], and [Dha, Dha].

[Dhin, Dha], [Dhin, Dhi], [Dhin, k], [Dhin, Avagraha], and [Dhin, Dhin].

[Dhi, Dha], [Dhi, Dhin], [Dhi, k], [Dhi, Avagraha], and [Dhi, Dhi].

There are 12 + 3 = 15 (fifteen) possibilities. The 12 possibilities are due to the regular permutations of Dha, Dhin and Dhi *Bols* for two *Matras* while repetition of each *Bol* like [Dha, Dha] etc. comprise three possibilities that are added. So, totally there are 15 possibilities of *Sam Pratyangas*.

All the options starting with either k or Avagraha are not acceptable such as [k, Dha], [k, Dhin], [k, Dhi], [k, Avagraha] and [Avagraha, Dha], [Avagraha, Dhin], [Avagraha, Dhi], [Avagraha, k]. Similarly, [k, k], and [Avagraha, Avagraha] are not allowed as *Sam Pratyangas* so they are not included here.

General *Pratyangas* for two *Matras*:

[Dha, Dhin], [Dha, Dhi], [Dha, k], [Dha, Avagraha], and [Dha, Dha].

[Dhin, Dha], [Dhin, Dhi], [Dhin, k], [Dhin, Avagraha], and [Dhin, Dhin].

[Dhi, Dha], [Dhi, Dhin], [Dhi, k], [Dhi, Avagraha], and [Dhi, Dhi]. [k, Dha], [k, Dhin], [k, Dhi].

[Avagraha, Dha], [Avagraha, Dhin], [Avagraha, Dhi].

There are 21 (Twenty-one) Pratyangas possible for two Matras.

[k, Avagraha], [k, k], and [Avagraha, k], [Avagraha, Avagraha] are not allowed as Pratyangas.

Sama Pratyangas for three *Matras*:

Total 22 possibilities starting with Dha are as follows.

[Dha, Dhin, Dhi], [Dha, Dhi, Dhin], [Dha, Dhin, Dha], [Dha, Dhi, Dha], [Dha, Dha, Dhin], [Dha, Dha, Dhi], [Dha, Dhin, Dhin], [Dha, Dhi, Dhi].

[Dha, Dhin, k], [Dha, Dhi, k], [Dha, k, Dhin], [Dha, k, Dhi], [Dha, k, Dha], [Dha, Dha, k].

[Dha, Dhin, Avagraha], [Dha, Dhi, Avagraha], [Dha, Avagraha, Dhin], [Dha, Avagraha, Dhi], [Dha, Avagraha, Dha], [Dha, Dha, Avagraha].

[Dha, Avagraha, k], [Dha, k, Avagraha].

Total 22 possibilities starting with Dhin are as follows.

[Dhin, Dha, Dhi], [Dhin, Dhi, Dha], [Dhin, Dha, Dhin], [Dhin, Dhi, Dhin], [Dhin,

Dhin, Dha], [Dhin, Dhin, Dhi], [Dhin, Dha, Dha], [Dhin, Dhi, Dhi].

[Dhin, Dha, k], [Dhin, Dhi, k], [Dhin, k, Dha], [Dhin, k, Dhi], [Dhin, k, Dhin], [Dhin, Dhin, k].

[Dhin, Dha, Avagraha], [Dhin, Dhi, Avagraha], [Dhin, Avagraha, Dha], [Dhin, Avagraha, Dhi], [Dhin, Avagraha, Dhin], [Dhin, Dhin, Avagraha].

[Dhin, Avagraha, k], [Dhin, k, Avagraha].

Total 22 possibilities starting with Dhi are as follows.

[Dhi, Dha, Dhin], [Dhi, Dhin, Dha], [Dhi, Dha, Dhi], [Dhi, Dhin, Dhi], [Dhi, Dhi, Dha], [Dhi, Dhi, Dhin], [Dhi, Dha, Dha], [Dhi, Dhin, Dhin].

[Dhi, Dha, k], [Dhi, Dhin, k], [Dhi, k, Dha], [Dhi, k, Dhi], [Dhi, k, Dhi], [Dhi, Dhi, k].

[Dhi, Dha, Avagraha], [Dhi, Dhin, Avagraha], [Dhi, Avagraha, Dha], [Dhi, Avagraha, Dhin], [Dhi, Avagraha, Dhi], [Dhi, Dhi, Avagraha].

[Dhi, Avagraha, k], [Dhi, k, Avagraha].

Thus, there are 66 possibilities of *Sam Pratyangas* for three *Matras*. For general *Pratyangas* these 66 options are valid but few more possibilities will be added. There can be *Pratyangas* starting with k and Avagraha. So, all such possibilities are worked out as follows.

[k, Dha, Dhin], [k, Dha, Dhi], [k, Dhin, Dha], [k, Dhi, Dha], [k, Dha, Dha], [k, Dhin, Dhin], [k, Dhi, Dhi].

[k, Dha, k], [k, Dhin, k], [k, Dhi, k], [k, Dha, Avagraha], [k, Dhin, Avagraha], [k, Dhi, Avagraha].

[Avagraha, Dha, Dhin], [Avagraha, Dha, Dhi], [Avagraha, Dhin, Dha], [Avagraha, Dhi, Dha], [Avagraha, Dha, Dha], [Avagraha, Dhin, Dhin], [Avagraha, Dhi, Dhi].

[Avagraha, Dha, k], [Avagraha, Dhin, k], [Avagraha, Dhi, k], [Avagraha, Dha, Avagraha], [Avagraha, Dhin, Avagraha], [Avagraha, Dhi, Avagraha].

There are 13 possibilities starting with k and 13 possibilities starting with *Avagraha*. So, if these 26 possibilities are added to earlier *Sam Pratyanga* possibilities the total number of possibilities for general *Pratyangas* come about 92. Thus, it can be said that there are 92 options for general *Pratyangas* made up of three *Matras*.

In the same fashion number of possibilities for four *Matras* can be computed for *Sam Pratyangas*. Above description provides the details of *Sam Pratyangas* and general *Pratyangas* for one *Matra*, two *Matras* and three *Matras*. For four *Matras* the number of possibilities for *Sam Pratyangas* come about 300 which itself is a big number. Giving a list of all these *Sam Pratyangas* will consume a huge space and therefore details of all these possibilities are not provided here for the sake of brevity. Contemporary *Talas* do not have five *Matra Pratyangas* and therefore they are not computed here.

Nava (Nine) *Gana Talas*

Previous passages provide a detailed description of all the basic concepts related to *Talas*. *Natyashastra* describes 108 *Talas*. *Sangit Ratnakara* provides a list of 120 *Talas* along with the *Meru Khanda Prastara* for all the *Talas*. However, contemporary music in North India, as well as Carnatic music, have developed new systems of *Talas*. North Indian music has *Talas* such as *Tritala, Eka Tala, Jhapa Tala, Rupaka Tala* and so forth. Carnatic music has the well-established scheme of *Suladi Sapta Talas*. These *Talas* are of relatively recent origins. They are considered simplified versions of complicated ancient *Prabandha Talas*. Apart from *Suladi Sapta Talas* there exist popular *Talas* called *Chapu Talas*. These are further simplified versions and deviate from theancient *Talas*. Interestingly, currently there is no unifying system in place that can cover all the contemporary *Tala* practices and also accommodate the virtues of ancient principles of *Tala*. Following is the generative computational system of nine classes of *Talas* that can accommodate all the existing *Talas*: North Indian and Carnatic *Talas* as well as the system can accommodate the ancient *Talas* as well.

The *Nava Gana Tala* system in GTIM is inspired by the concepts and principles of *Dasha Pranas* mentioned in the tradition, especially with the concept of *Jati*. So, this system is mostly consistent with the ancient systems of *Talas* and provides the scope for reinterpreting ancient *Talas*. This system is named the *Nava Gana Tala* System of Indian *Talas*. The *Ganas* are nothing but the '*Jatis*' of earlier ancient systems with appropriate re-purposing, suitable for contemporary Indian music. The new scheme of *Talas* is developed and tested using an Artificial Intelligence (AI) system called *AI-Tala* and can generate new *Talas* as well as the system can play and render existing contemporary *Talas*. The *Sanskrit* term for the computer is `*Samganaka*'. The new scheme of *Talas* is tested by computers and since a lot of computing has been involved in developing the scheme and therefore the term '*Gana*' seems appropriate. '*Gananm*' means computing in *Sanskrit*. Accordingly, the description of *Nava Gana Talas* is as follows.

Nine *Ganas* (classes) of the new system are as follows: *Tryashra Gana, Chatarshra Gana, Khanda Gana, Tryashra Guru Gana, Mishra Gana, Chatarshra Guru Gana, Sankirna Gana, Khanda Guru Gana,* and the last *Gana* is *Prakirna Gana. The Prakirna Gana* includes the *Talas* that are not covered under the first eight *Ganas*. During olden days there was a *Jati* named '*Divya Samkirna*' that is well documented, there are many folk *Talas* that are popular in folk performances, similarly there are many 'technically possible' *Talas* of different types which may evolve in future. There are *Talas* in the Carnatic music that have only one *Anga* such as the *Eka Tala* of Carnatic music. Such *Talas* cannot be classified under first eight *Ganas*. All such *Talas* are covered under the *Prakirana Gana*.

The names of the *Ganas* are based on the number of *Matras* in the first *Anga* of the *Tala*. A *Tala* can have any number of *Angas* but the most important condition is that the pattern of the *Tala Bols*, and *Pratyangas* in the first *Anga* will be preserved and repeated in other *Angas* of the *Tala* with appropriate variations governed by certain norms. There can be *Upangas* in a *Tala*. *Upangas* need not follow the same pattern. The number of *Matras* or beats for *Tala* is fixed. The first *Anga* of a

Tala is the 'Signature' *Anga* and the rest of the *Angas* will follow the same pattern while adhering to the norms of *Vibhagas*, *Sama, Kala, Tali, Khali* and *Upangas* if any. The standard norms are already discussed in detail. *Tala Bols* are structured according to these norms. However, certain salient features of each of the above-mentioned *Ganas* are described below.

Tryashra Gana: Number of *Matras* in each *Anga* in this *Gana* is three. It can have a following *Prastara patterns*: *Sama Prastara* [3], *Anuloma Prastara* [1,2] and *Viloma Prastara* [2,1]. There can be an *Upanga* with one or two *Matras* or beats.

Chatarashra Gana: Number of *Matras* in each *Anga* in this *Gana* is four. It can have a following *Prastara* patterns: *Sama Prastara* [4], *Anuloma Prastara* [1,3] and *Viloma Prastara* [3,1]. The *Sama Prastara* [2,2] is technically valid but it is not recommended because it may give the impact of *Dwyashra Tala*. There can be an *Upanga* with one or two beats. The *Anuloma Prastara* [1,3] and the *Viloma Prastara* [3,1] are slightly difficult to practice and need high level of skill.

Khanda Gana: Number of *Matras* in each *Anga* in this *Gana* is five. It can have a following *Prastara* patterns: *Anuloma Prastara* [1,4], [2,3] and *Viloma Prastara* [4,1], [3,2]. *Sama Prastara* [5], is technically acceptable in this *Gana* but very rarely this *Prastara* is used in contemporary *Talas*. There can be an *Upanga* with one or two beats. The *Anuloma Prastara* [1,4] and the *Viloma Prastara* [4,1] are slightly difficult to practice and need high level of skill.

***Tryashra Guru Gana*:** Number of *Matras* in each *Gana* is six. It can have a following *Prastara* patterns: *Anuloma Prastara* [2,4] and *Viloma Prastara* [4,2]. There is no *Sama Prastara* because [3,3] *Prastara* will conflict with *Tryashara Gana* and [6] *Prastara* is too long to use. The [2,2,2] *Prastara* is not acceptable as a *Sama Prastara* because it may generate the effect of *Dwyashra Tala*. There can be *Upangas* with one or two beats.

Mishra Gana: Number of *Matras* in each *Anga* in this *Gana* is seven. It can have a following *Prastara* patterns: *Anuloma Prastara* [1,3,3], [1,2,4], [3,4] and *Viloma Prastara* [3,3,1], [4,2,1], [4,3]. The *Mishra Prastara* [2,3,2] is possible with this *Gana*. There can be an *Upanga* with one or two beats.

***Chatarashra Guru Gana*:** Number of *Matras* in each *Anga* of this *Gana* is eight. It can have a following *Prastara* patterns: *Anuloma Prastara* [1,3,4], [2,2,4] and *Viloma Prastara* [4,3,1], [4,2,2]. The *Sama Prastara* [2,2,2,2] is not allowed in this *Gana* because it will create the impact of *Dwyashra Gana* and *Sarala Prastara* [4,4] will conflict with *Chatarashra Gana* and [8] is too long to be used as an *Anga*. The *Mishra Prastara* [2,4,2] is possible with this *Gana*. There can be an *Upanga* with one or two beats. Such a long *Tala* can have two *Vibhagas* made up of one *Anga* each. Multiple *Angas* will be difficult to manage. The

Anuloma Prastara [1,3,4] and the *Viloma Prastara* [4,3,1] are slightly difficult to practice and need high level of skill.

Sankirna Gana: Number of *Matras* in each *Anga* in this *Gana* is nine. It can have a following *Prastara* patterns: *Anuloma Prastara* [2,3,4] and *Viloma Prastara* [4,3,2].

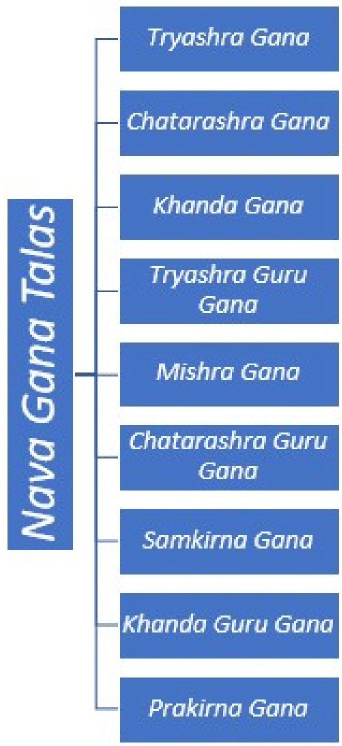
The *Sama Prastara* [3,3,3] is not allowed in this *Gana* because it will conflict with the *Tryashra Gana Prastara* and [9] is too long to be used. The *Mishra Prastara* [2,4,3] or [3,4,2] are possible with this *Gana*. There can be an *Upanga* with one or two beats. The *Samkirna Jati/ Gana* is too long to manage and does not appear to be relevant to contemporary music however, it is included here because it is thoroughly documented in the traditional literature of Carnatic music.

Khanda Guru Gana**:** Number of *Matras* in each *Anga* of this *Gana* is ten. It can have a following *Prastara* patterns: *Anuloma Prastara* [2,4,4], [3,3,4], [2,3,5] and *Viloma Prastara* [4,4,2], [4,3,3], [5,3,2]. *Sama Prastara* [10], is too long to be

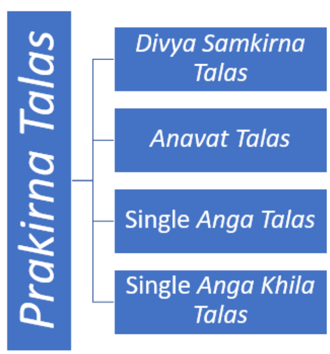
used. *The Mishra Prastara* [3,4,3], [2,5,3], [3,5,2] and [4,2,4] are possible with this *Gana*. There can be an *Upanga* with one or two beats. Such a long Tala ideally should have only two *Angas/ Vibhagas*.

Prakirna Gana**:** This *Gana* is dedicated to all the other possible *Ganas* or varieties of *Talas*. During ancient times there was a *Jati* called '*Divya Sankirna Jati*'. This *Jati* is not considered separately in the first eight *Ganas* because it appears practically impossible to keep track of *Anga* with eleven *Matras* during the performance. In principle, there can be *Ganas* with *Angas* having thirteen *Matras*, fifteen *Matras* and so on. Such theoretical possibilities always exist. All such *Talas* and other large or irregular *Talas* are considered *Anavat Talas*. The *Prakirna Gana* tries to accommodate all such possibilities. Similarly, in the Carnatic system of *Talas,* there exists a category of *Talas* that have only one *Anga*. The best example of this category is *Eka Tala*. It has only one *Anga* but based on the number of *Matras* in the *Tala*, there can be variations such as *Tryasra Jati Eka Tala* or *Khanda Jati Eka Tala*. Thus, *Eka Tala* of the Carnatic system is also a part of this *Prakirna Gana*. There exists one more possibility of *Talas* that have a single *Anga*. Such *Talas* have a single *Anga* but within the *Anga,* there can be *Pratyangas* and by following the logic of *Vibhagas*, *Kal* or *Khali* status can be assigned to certain *Pratyangas*. Such *Talas* could be small *Talas* of up to ten *Matras*. All such *Talas* are called single *Anga Khila Talas* in the *Nava Gana* system. They are also part of *Prakirna Gana*. Thus, the *Nava Gana Tala* system is a comprehensive system of *Talas* that covers all the possibilities of *Tala* generation and classification. It has the scope for accommodation for all the possible future *Talas* and thus the system is scalable.

Nava Gana Talas



Prakirna Talas:



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CHAPTER 22

Formal Representation of *Tala*

Introduction

A musical performance begins at certain time, irrespective of whether it is a vocal, instrumental or a purely percussion-based performance. In any case the *Tala* provides a temporal structure to the musical performance. It may be assumed that any musical performance begins at T0 and ends at Tn where T0 is an initial time of the performance and Tn is the end time of the performance. Here T refers to the entire time allocated for the performance where a sequence of multiple small performances can happen. Here the T stands for the *Kaala* as mentioned in the *Dasha Pranas* of *Tala*. Ideally, a performer is expected to plan and design the entire duration of time 'T' allocated for the performance and many performers do think about the performances from this perspective. Thus, T can have T1, T2 ... Tn instances of small parts. In the following passages, the description is provided for such individual instances Ti. So, for each instance Ti we define initial time as t0 and the ending time as tn. With this representation we can say that a musical composition starts at t0 and ends at tn. A performer divides this duration into small units and each unit is called an *Avartana* or a cyclical unit of a *Tala*. So, there are multiple *Avartanas* in a musical performance.

In a musical performance, the tempo of the *Avartana* may vary or change but the structure of the *Avartana* remains intact because the structure of the *Avartana* is based on the *Tala*. In simple terms, the *Avartana* (a cycle of beats) can be played in *Vilambita* (slow) or *Madhya* (medium) or *Druta* (fast) tempo but the *Tala* remains the same. Let us assume that *Avartana* begins at t0 and ends at tk, so 'k' becomes the unit time for the *Tala Avartana*. As a standard norm 'k' is the unit of duration for the *Madhya Laya* or the medium tempo. For the *Vilambit Laya* the *Avartana* will be of 2*k duration while for the *Druta Laya* or the fast tempo, the *Avartana* will take lesser time as k/2. This time duration 'k' is further divided into smaller units called *Matra* or a beat. *Matra* is considered as the basic unit of a *Tala* and the *Avartana* duration is counted in terms of *Matras* or beats. So, for instance, *Tri-Tala* is made up of 16 *Matras* or beats. It means that each *Avartana* of *Tri-Tala* is played for 16 beats.

With this prelude we try to define a few basic concepts related to *Tala* from a temporal as well as psycho-acoustic perspective. The previous chapter on *Tala* discussed all the important concepts related to Indian *Tala* from a musical judicium. The following disquisition is important from computational perspective that can capture the temporal and the psycho-acoustic perspective and therefore a formal language for Indian *Talas* is developed. The formal description of *Tala* is as follows.

Modelling *Tala*

Tala can be formally represented as a tuple. A *Tala* can be envisioned as a 6-tuple made up of total number of *Matras* in the *Tala*, number of *Matras* of the *Anga* (*Angas* is a basic unit of *Tala* that has fixed number of *Matras*), and the number of *Matras* of an *Upanga* if any. *Tala* also has one, two or three *Vibhagas.* Each *Angas* has a characteristic pattern called *Prastara*. Finally, and very importantly there exists a characteristic *Bol* structure for the *Anga*. All this can be represented formally as follows.

Tala can be represented as *Tala* = $[N, N_A, N_U, V, P_A, B_A]$.

N = Number of *Matras*.

N_A = Number of *Matras* in the signature *Anga* or in any *Anga* of the *Tala*.

N_U = Number of *Matras* of *Upanga* where $N_U = N \bmod N_A$.

V stands for *Vibhagas* where $V \in \{1, 2, 3\}$ and $V \mid (N-N_U)/ N_A$.

P_A = a *Prastara* pattern, a tuple of natural numbers specifying subdivisions of one *Anga* (Signature *Anga*) where

$$\sum_{i \in P_A} i = N_A$$

B_A = a tuple of length N_A showing *Bols* of an *Anga* following the pattern of P_A.

Following is an elaboration on the above-mentioned definitions of the elements of a *Tala* tuple.

There are four types of *Angas* in a *Tala* having same structure of *Bols* that brings in the consistency in the rhythmic patterns of a *Tala*. B_A stands for an *Anga* so the four types of *Angas* can be defined as B_{AS}, B_{AK}, B_{AT}, B_{AKH}. The B_{AS} is a *Sam Anga*.

It is a defining feature of a *Tala*. There is a counterpart of B_{AS} that is called the *Kal Anga*. It can be defined as B_{AK}. This is always in the beginning of the second *Vibhaga* of a *Tala*. The third type of *Anga* is called *Tali Anga* which is represented as B_{AT} which is similar to the B_{AS} in every respect except the fact that its first *Matra* is not called a *Sam Matra*. The fourth type of *Anga* is called *Khali Anga* B_{AKH} which is similar to the B_{AK} in every respect except that the first *Matra* of it is not called the *Kal Matra*.

In the above description of a *Tala* N stands for the total number of *Matras* in a Tala. N_A stands for number of *Matras* of the main *Anga* which is also known as the signature *Anga*. A *Tala* also can have an *Upanga*, either at the end as the additional part of the *Tala* or it can come in the beginning or it can come before the *Kal Vibhaga*. N_U stands for the number of *Matras* of the *Upanga*. *Upanga* is a characteristic feature of many Carnatic *Talas* while in North Indian music it is rarely found. Some performers explore and experiment by adding a half *Matara* or a quarter *Matra* at the end of the *Aavartana*. This may be considered as an *Upanga* otherwise, in North Indian music an *Upanga* should be considered as having zero *Matras*.

Tala has *Vibhagas*. Normally, there can be two or three *Vibhagas* of a *Tala,* however in a Carnatic music some *Talas* like *Eka Tala* have only one *Vibhaga* and only one *Anga*. Knowing the number of *Vibhagas* helps in deciding the position of *Kal* in the *Tala* structure when total number of *Angas* are divisible by 2 or 3. Let us understand this process with the example of a *Tala* with 12 *Matras* and how multiple options unfold. For instance, if there are 12 *Matras* in a *Tala* then there can be three *Angas* of 4 *Matras* each as [[4],[4],[4]]. This will be *Chatarashra Gana Tala* because there are four *Matras* in each *Anga*. Here each *Anga* is treated as a *Vibhaga*. So, the first *Anga/ Vibhaga* will be a *Sam Vibhaga*, the second *Anga/ Vibhaga* will be the *Kal Vibhaga* and the third *Anga/ Vibhaga* will be the *Mishra Vibhaga*. It will look like [[*Sam*- 4], [*Kal*- 4], [*Mishra*- 4]]. Instead of 12 *Matras* if there are 15 *Matras* and we need the same *Chatarashra Tala* then we have to add an *Upanga* of three *Matra*s at the end. Then the same *Tala* with *Upanga* will look like [[*Sam*- 4], [*Kal*- 4], [*Mishra*- 4], [*Upanga*- 3]]. Interestingly *Upanga* of three *Matras* can be split into two parts as [[2], [1]]. Now there is a possibility that the first part of two *Matras* can be an *Aantar-Upanga* and can be placed before the *Kal Vibhaga*. Then the same *Tala* will look like [[*Sam*- 4], [*Antar-Upanga*- 2], [*Kal*- 4], [*Mishra*- 4], [*Upanga*- 1]]. Normally if the residue of the *Matras* is more than two after *Angas* are decided then it can be split as shown in this case.

As another alternative there can be four *Angas* of three *Matras* each. In this case four *Angas* are divided into two *Vibhagas* of 3+3 and 3+3 *Matras* each where the first *Vibhaga* will be the *Sam Vibhaga* and the second *Vibhaga* will be the *Kal Vibhaga*. Here each *Vibhaga* has two *Angas* as their constituents. This will be the *Tryashra Gana Tala* as [[[Sam- 3], [tali-3]], [[Kal- 3], [khali-3]]] because each *Anga* has three *Matras*. In this case if there are 14 *Matras* instead of 12 then we will have one *Upanga* of two *Matras* at the end of the *Tala* as [[[*Sam*- 3], [*Tali*-3]], [[*Kal*- 3], [*Khali*-3]], [[*Upanga*- 2]]].

Anga Prastara

In the above description of a *Tala* P_A stands for the *Anga Prastara* for the signature *Anga* but eventually the same pattern of *Prastara* is followed for all the other *Angas* with some variations.

P_A is a k-tuple such as $P_A = (p_1, p_2, ...p_k)$. However, in practice $0 < k < 4$ as far as *Angas* of most of the contemporary *Talas* are concerned. We may get references of ancient *Talas* where there are more than three *Pratyangas* in an *Anga*.

There are four types of *Prastaras* possible. If p_i is the argument in a *Prastara* $P_A = (p_1, p_2, ...p_k)$ then four patterns of such arguments are possible. These are *Sarala Prastara, Anuloma Prastara, Viloma Prastara,* and the *Mishra Prastara.* Following is the formal description of all four *Prastaras*.

Sarala Prastara: When all the members of the tuple are equal then it is called a *Sarala Prastara* for example (1), or (2, 2) or (3, 3, 3) all are the examples of *Sarala Prastaras*. This may be represented as follows.

If the given *Prastara* is 1-tuple *Prastara* then $P_A = (p_i \mid p_i \in N)$.

If the given *Prastara* is 2-tuple *Prastara* then $P_A = (p_1, p_2$ where p_1 and $p_2 \in N$ and $p_1 = p_2)$.

If the given *Prastara* is 3-tuple *Prastara* then $P_A = (p_1, p_2, p_3$ where p_1, p_2 and $p_3 \in N$ and $p_1 = p_2 = p_3)$.

Above are the specific cases of *Sarala Prastaras* mostly used in Indian *Talas* because number of *Pratyangas* in contemporary *Talas* does not exceed three *Pratyangas*. A generic representation for *Sarala Prastara* is $P_A = (p_1 = p_2, ... = p_k)$ where $p_i \in N$.

Anuloma Prastara: When all the members of the tuple are arranged in an ascending hierarchy then it is called an *Anuloma Prastara* for example (2, 3), (2, 2, 3), (2, 3, 3) or (2, 3, 4) all are the examples of *Anuloma Prastaras*. This may be represented as follows.

If the given *Prastara* is 2-tuple *Prastara* then $P_A = (p_1, p_2$ where p_1 and $p_2 \in N$ and $p_1 \leq p_2)$.

If the given *Prastara* is 3-tuple *Prastara* then $P_A = (p_1, p_2, p_3$ where p_1, p_2 and $p_3 \in N$ and $p_1 \leq p_2 \leq p_3)$.

Above are the specific cases of *Anuloma Prastaras* mostly used in Indian *Talas* because number of *Pratyangas* in contemporary *Talas* does not exceed three *Pratyangas*. A generic representation for *Anuloma Prastara* is $P_A = (p_1, \leq p_2, \ldots \leq p_k)$ where $p_i \in N$.

Viloma Prastara: When all the members of the *Prastara* tuple are arranged in descending hierarchy then it is called a *Viloma Prastara* for example (3, 2), (3, 3, 2), (3, 2, 2) or (4, 3, 2) all are the examples of *Viloma Prastaras*. This may be represented as follows.

If the given *Prastara* is 2-tuple *Prastara* then $P_A = (p_1, p_2$ where p_1 and $p_2 \in N$ and $p_1 \geq p_2)$.

If the given *Prastara* is 3-tuple *Prastara* then $P_A = (p_1, p_2, p_3$ where p_1, p_2 and $p_3 \in N$ and $p_1 \geq p_2 \geq p_3)$.

Above are the specific cases of *Viloma Prastaras* mostly used in Indian *Talas* because number of *Pratyangas* in contemporary *Talas* does not exceed three *Pratyangas*. A generic representation for *Viloma Prastara* is $P_A = (p_1, \geq p_2, \ldots \geq p_k)$ where $p_i \in N$.

Mishra Prastara: When all the members of the tuple are not arranged in ascending or descending hierarchy then it is called a *Mishra Prastara* for example (3, 2, 3) or (2, 3, 2) or (4, 2, 3) all are the examples of *Mishra Prastaras*. This may be represented as follows.

If the given *Prastara* is 3-tuple *Prastara* then $P_A = (p_1, p_2, p_3$ where p_1, p_2 and $p_3 \in N$ and $p_1 > p_2 < p_3)$.

If the given *Prastara* is 3-tuple *Prastara* then $P_A = (p_1, p_2, p_3$ where p_1, p_2 and $p_3 \in N$ and $p_1 < p_2 > p_3)$.

If the given *Prastara* is 3-tuple *Prastara* then $P_A = (p_1, p_2, p_3$ where p_1, p_2 and $p_3 \in N$ and $p_1 > p_2 < p_3)$.

Above are the valid cases of *Mishra Prastaras* mostly used in Indian *Talas* because number of *Pratyangas* in contemporary *Talas* does not exceed three *Pratyangas*. Generic representation of *Mishra Prastaras* can be understood as the absence of *Sarala Prastara, Anuloma Prastara* or *Viloma Prastara*. It means by default any *Prastara* tuple is a *Mishra Prastara* tuple if these three patterns of *Prastaras* are absent.

In the above *Tala* description, B_A stands for the *Anga* of a *Tala* and B_{AS} stands for the characteristic *Bol*-structure of the signature *Anga*.

As it is already mentioned that it is very difficult to develop instrument-independent notational symbol system for *Tala* the above-mentioned categorization of *Tabla Bols* is done to get the clarity about the range and scope of notational symbols.

There are many *Tala* instruments that use different sets of *Bols* and their range of usage of these *Bols* is relatively limited. *Tabla* is an instrument that has the widest possible range of the usage of *Bols*. It has *Bols* for highly accented weighted strokes such as *Dha* and it has *Bol* such as *Dhin* that has impact of weighted stroke combined with the effect of soft stroke as well. *Tabla* has the *Bol* '*k*' or '*ka*' for stop and *Avagraha* for the absence of a stroke and so on. Therefore, taking *Tabla Bols* as a reference set has many advantages. Probably *Mridangam* is the next best instrument. But other *Tala* instruments are very limited in their scope as far as the range of applications of *Bol* is concerned. After studying the rhythm related sonic qualities of *Tabla* strokes it is possible to connect properties of *Tabla Bols* to the traditional *Chhanda Shastra* vocabulary. Taking the inspiration from these sources a new vocabulary for *Tala* representation is developed as follows.

Tala Bols

As it is known *Matra* is the unit of measuring time duration. *Bol* is slightly complex unit. Apart from duration it includes other aspects such as accent, volume, timbre, resonating impact and the use of multiple dimensions of the instrument for the *Tala* strokes (analogous to how the *swara* attribute was defined). *Tabla* has two parts as *Daya* and *Baya* or the *Mridangam* has two sides to produce *Tala Bols*. Finally, it makes sense to use *Tala Bols* that have *Vajan* or the 'Weight' as discussed in the previous chapter. as the basic elements of the formal system for *Nava Gana Talas*. To keep the formal language of *Tala* lean, simple and parsimonious, the basic set of *Bols* is kept very small. This set is as follows.

BasicBols = {*Guru, Laghu, Madhya, Ardha, Avagraha*}.

As discussed above there are two expressions of each of the above types of *Bols* as the *Maha Prana* expression and the *Alpa Prana* expressions. The *Maha Prana Bols* are produced by using more than one sides of the instrument while *Alpa Prana Bols* are produced by using just one side of the instrument. Therefore, *Maha Prana Bols* are more resonating in impact while the *Alpa Prana Bols* are plain and with less resonance. This is a simplified description of *Maha Prana Bols* and *Alpa Prana Bols* because these *Bols* also carry many complex sound properties. So, the above set can be modified as the set of basic *Bols* with expressions as follows.

BasicBolsExpr = {*GuruMP, LaghuMP, MadhyaMP, GuruAP, LaghuAP, MadhyaAP, Ardha, Avagraha*}.

Here the extension MP stands for the *Maha Prana* and AP stands for the *Alpa Prana*. As we substitute these members of the BasicBolsExpr by corresponding *Tabla Bols*, it becomes easy to understand the significance of this set. After substitution the set will look like as follows.

BasicBolsExpr = {*Dha* (*GuruMP*), *Dhi* (*LaghuMP*), *Dhin* (*MadhyaMP*), *Ta* (*GuruAP*), *Ti* (*LaghuAP*), *Tin* (*MadhyaAP*), *Ka* (*Ardha*), *Avagraha*}.

Ka and *Avagraha* are neutral because they do not have either *Maha Prana* expression or *Alpa Prana* expression. Apart from these basic *Bols*, there exists one more set of *Bols* called neutral *Bols*. This is very important set because the members of this set can be used to substitute *Maha Prana Bols* as well as *Alpa Prana Bols* in specific conditions. This set is called *Ubhay Bols* and shown as follows.

UbhayBols = {*Tirikit*} there can be few more members in this set such as *Na, Tiri, Kit*, etc. but for simplicity only one member is shown.

With this basic understanding we can proceed to develop a formal language for *Talas*.

Formal System for *Bols*

As already mentioned, *Tabla Bols* are used to represent the *Tala Bols* because they are well-established and the readers are familiar with them. The following list of *Bols* represents the *Bols* used by practitioners but it is not exhaustive in any sense however, it certainly indicates all the required parameters necessary for a formal system of *Tala*. The *AITala* system is based on more than 40 *Bols* required for *Tabla* generation. That includes *Laghu Bols, Guru Bols, Ardha Bols, Madhya Bols, Avagraha*, and conjuncts- combined *Bols*. This covers the entire range. Many *Gharanas* have different nomenclatures for some *Bols*. For a formal system, nomenclatures are not so important on the other hand the sound entities that are represented are more important. So, all care is taken to capture all the possible *Bols* in the system. However, some *Gharana*-specific *Bols* may not be included in this system but always such *Bols* can be added at later stage. The system is open and scalable. To keep the system, lean and elegant, only minimal nomenclatures are therefore used in the formal system. The exhaustive list of *Bols* will be as follows.

All *Bols* = [*Dha, Na, Dhin, Dhi, Dhagi, Ghay, Gi, Ta, Tin, Ti, Tagi, Tay, Tey, Ri, Ki, TT, Tiri, Kit, Tirkit, Ka, Avagraha*]. This list can be split into small lists representing various aspects such as *Sama Bols*, *Tali Bols*, *Khali Bols* and neutral *Bols* called *Ubhay Bols*. This is done as follows.

Sama Anga Bols = [Dha, Dhin, Dhi, Ka, Avagraha].

Kal Anga Bols = [Ta, Tin, Ti, Ka, Avagraha].

Tali Anga Bols = [Dha, Na, Dhin, Dhi, Dhagi, Ghay, Gi, Ka, Avagraha].

Khali Anga Bols = [Ta, Tin, Ti, Tagi, Tay, Tey, Ka, Avagraha].

Ubhaya Anga Bols = [Ri, Ki, TT, Tiri, Kit, Tirkit, Ka, Avagraha]

With the set of all *Bols* and its other subsets as mentioned above the required resources for proceeding for developing the formal language for *Tala* is sufficient. Now it is possible to define and specify various other aspects of this formal language as follows.

For generating signature *Anga* for a *Tala*, *Bols* of the *Sama Matra* is very important. It can be selected from the following set.

Sama Matra Bols = [Dha, Dhin, Dhi].

Kal Matra Bols = [Ta, Tin, Ti].

As the *Sama Matra Bol* is selected it decides the *Kala Matra Bol*. *Kala Matra Bol* is a counter part of the *Sama Matra Bol*. It is decided as per the set of ordered pairs of *Bols* as follows. This set of *Bol* pairs is very important. The set of ordered pairs of *Bols* is as follows.

Ordered Pairs of *Bols* = [<Dha, Ta>, <Dhin, Tin>, <Dhi, Ti>, <Dhagi, Tagi>, <Ka, Ka>, <Avagraha, Avagraha>, <Na, Ta>, <Ghay, Tay>, <Gi, Tey>, <Ri, Ri>, <Ki, Ki>, <TT, TT>, <Tiri, Tiri>, <Kit, Kit>, <Tirkit, Tirkit>].

In each ordered pair the first member is the *Bol* that can be used for the *Bhari* part of the *Tala* that is the *Sam Anga* or the *Tali Anga* and the second member can be used for the *Khali* part of the *Tala* that is the *Kal Anga* or the *Khali Anga* of a *Tala*.

Bhari Bols and *Khali Bols*

Tala is an interesting structure that has at least two or three major sections called *Vibhagas*. The first section is called the *Sama* section or *Sama Vibhaga*. It is made up of number of *Angas*. There can be any number of *Angas* in a section but practically, more than two *Angas* become unmanageable. The first *Anga* of the *Sama* section or *Sama Vibhaga* is the main *Anga* of the *Tala*. It is also called a 'signature *Anga*' because of the *Bol* structure of the signature *Anga* decides the character of the rest of the *Angas* and the *Vajan* of the *Tala*. A *Tala* has another section called *Kal* section or *Kal Vibhaga*. It has the same structure as the *Sam Vibhaga* except the fact that the *Bols* of the *Kal Vibhaga* are the counter parts of the *Bols* from the *Sama Vibhaga*. Therefore, the following set of *Bol* pairs is important. For every *Bol* from the *Sama Vibhaga* there will be its counterpart in the *Kal Vibhaga* as a member in the same order. If *Dha* is the first member of the signature *Anga* of the *Sama Vibhaga* then *Ta* will be the first member of the *Kal* signature *Anga* of the *Kal Vibhaga*.

Formal Language for *Bols*

Now let us try to define and generate the *Bols* for *Angas* as follows. *Bols* of the *Anga* are anchored in *Anga Prastara* patterns.

Let us assume that SMB = [Dha, Dhin, Dhi] a set of *Sama Matra Bols* and

Let KMB = [Ta, Tin, Ti] as a set of *Kal Matra Bols*.

Let SAB = [Dha, Dhin, Dhi, Ka, Avagraha] as *Sama Anga Bols*

Let KAB = [Ta, Tin, Ti, Ka, Avagraha] as *Kal Anga Bols*

Let UAB = [Tirkit] this can have other members such as *Ti, Ri, Ki*, etc.

It is possible to define a function angaGenS for generating a signature *Anga* for the *Tala* such that

angaGenS (P_A) = B_{AS} where $B_{AS} = (B_{p1}, B_{p2}, \ldots B_{pk})$.

where P_A is *Anga Prastara* as an input to the function and B stands for *Bol*, B_{AS} stands for *Bols* of *Sama Anga*, p stands for the *Prastara* value and k stands for the *Prastara* sequence number in P_A.

In this case B_{p1} is the *Sam Pratyangas* with $_{p1}$- tuple made up of *Bol* b_i such that $B_{p1} = (b_1, b_2, \ldots b_n)$ where k = p1 = 1 and for Bol b_i if i = 1 then $b_i \in$ SMB and if i > 1 then $b_i \in$ SAB. For any other *Pratyangas* if k> p1 then the *Bol* b_i should fulfil the condition that if i=1 then b ∈ UAB and if i>1 then $b_i \in$ SAB and other important condition is that any *Bol* should not be consecutively repeated thrice in the *Anga*. It means that $b_n \neq b_{n-1} \neq b_{n-2}$.

Similarly, functions for *Kal Anga, Tali Anga* and *Khali Anga* can be defined but there is a major difference. Input for the function angaGneS was $P_{A.}$ While for these three functions the input will be the output of angaGenS that is B_{AS}. This is because *Kal Anga, Tali Anga* and *Khali Anga* are based on the structure of the signature *Anga* of the *Tala*. So first let us define the function for Kal Anga as angaGenK.

angaGenK (B_{AS}) = B_{AK} where $B_{AS} = (B_{p1}, B_{p2}, \ldots B_{pk})$. Transforming B_{AS} to B_{AK} is easier because each *Bol* of B_{AK} is a counterpart of the *Bols* of B_{AS}. Let a set of all *Bols* for transformation be B. We can define a function to transform the *Bols* of *Pratyangas* as

transBPK (b): B → B. Here transBPK takes in a *Bol* 'b' from each *Pratyanga* of B_{AS} as an input and outputs a *Bol* by the following corresponding *Bols* given in the following list TransBPK to generate B_{AK}. TransBPK is the list of ordered pairs of *Bols* denoting transfer function.

TransBPK = [*Dha* → *Ta*, *Dhin* → *Tin*, *Dhi* → *Ti*, *Dhagi* → *Tagi*, *Ka* → *Ka*, *Avagraha*

→ *Avagraha*, *Na* → *Ta*, *Ghay* → *Tay*, *Gi* → *Tey*, *Ri* → *Ri*, *Ki* → *Ki*, *TT* → *TT*, *Tiri* → *Tiri*, *Kit* → *Kit*, *Tirkit* → *TirKit*].

Similarly, for generating a *Khali Anga* we can use the same function since the *Bols* of *Kal Anga* and the *Khali Anga* are the same. For the generating of a *Tali Anga,* we need to define similar function transBPT (b): B → B. Here transBPT takes in a *Bol* 'b' from each *Pratyanga* of B_{AS} as an input and outputs a *Bol* by the following corresponding *Bols* given in the following list TransBPT to generate B_{AT}.

TransBPT = [*Dha* → *Dha*, *Dhin* → *Dhin*, *Dhi* → *Dhi*, *Dhagi* → *Dhagi*, *Ka* → *Ka*, *Avagraha* → *Avagraha*, *Na* → *Na*, *Ghay* → *Ghay*, *Gi* → *Gi*, *Ri* → *Ri*, *Ki* → *Ki*, *TT* → *TT*, *Tiri* → *Tiri*, *Kit* → *Kit*, *Tirkit* → *TirKit*].

It can be seen that the original *Bols* of the signature *Anga* are not changed in the *Tali Anga* because *Sam Anga Bols* and the *Tali Anga Bols* are always the same in a *Tala* except the fact that the first *Bol* of the *Sama Anga* is called *Sama Bol* while the first *Bol* of *Tali Anga* is not called a *Sama Bol*.

With the above formal representation, most of the concepts related to *Tala* can be articulated in a logical and mathematical terms. As initially it was mentioned that *Tala* is a 6-tuple represented as *Tala* = [N, N_A, N_U, V, P_A, B_A]. With the above description, it is clear that each of the element of this tuple is described formally in a rigorous way. Formal representation helps in bringing clarity and removing any confusion to understand the technical subtleties.

The scope of the formal representation of *Tala* in this chapter is limited to the basic, core and theoretical concepts. Other operational concepts can be articulated in the same fashion based on the formal language thus developed in this chapter. *Tala* related concepts from the North and the South Indian music such as *Chakradar, Tihai, Gat, Mukhada, Toda, Kayada, Laggi, Rela, Palata, Tukada, Mukhada* etc. are too specific to certain styles or *Gharanas* and there is a great variance in practical applications in the performance. The formal language of *Tala* as developed in the above passages is capable of articulating these concepts. But since these concepts, though have generic definitions, they are practiced according to their *Gharanas* and therefore the formal description will have *Gharana*-specific variance. Capturing such a variance is beyond the scope of this book and therefore, the formal treatment of the *Tala* is concluded here. Developing a Gharana-neutral formal language for above concepts can be a very good research project.

Tala performance is conducted in two ways. Most of the times the percussion instruments are used as accompaniments where their role is to support the main performer and provide the *Tala* foundations or the *Tala* framework to the performance. There can be a full-fledged solo performance of *Tala* using a specific percussion instrument. In both the cases *Tala* structure is already envisioned and accordingly the *Talas* are performed. However, there is a major difference. When the main performer is a vocalist or an instrumentalist, the composition is set in a particular *Raga* and the *Tala* has a secondary role to play. While when there is a solo performance by a percussionist the composition is composed in a particular *Tala* and therefore, the *Tala* has the main role in the performance. The objective of this chapter is to develop a theoretical structure of a *Tala* and articulate it in a formal way. The presentation and performance of a *Tala*, either as an accompaniment or as a solo performance is not the focus of this chapter. No doubt it is an important part of the music but there exists a huge diversity of presentation styles of the *Tala* performances. One or two chapters cannot do justice to cover the presentational aspects of a *Tala*. The diversities exist in terms of genre, percussion instruments, North Indian and Carnatic styles of music, and diverse contemporary practices of percussion performances. Therefore, the scope of the discussion on *Tala* is delimited to the theory building and the formal representation of *Tala*.

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PART VIII
Bhairavi (Higher Sa)

Ch 23. Conclusions

CONCLUSIONS

GTIM: Significance and Contributions

'Generative Theory of Indian Music' (GTIM) as the name suggests focuses on articulating generative nature of Indian music. Some time back in 1983, a theory called generative theory of tonal music (GTTM) for Western music was developed by Fred Lerdahl and Ray Jackendoff. However, for Indian music no such attempt has been made. GTIM is the prime mover in this regard.

GTIM is anchored in Indian philosophy of *Advaita Vedant* and in this sense has very robust philosophical and theoretical foundations. As a single seed manifests into a majestic tree, GTIM argues that in the same fashion, a single swara *Shadja* manifests into the great Banyan tree of Indian music. GTIM validates this perspective in very systematic and in a step-by-step manner by developing a robust logical system for Indian music.

GTIM is a synthesis of the ancient wisdom gathered from *Naradiya Shiksha, Natyashastra* of Bharata, Matanga Muni's *Brihaddeshi*, *Sangita Ratnakara* of Sharangadeva and the advanced technology of Artificial Intelligence (AI). GTIM explicitly shows the theoretical consistency and connectivity among ancient treatises by unfolding the hidden aural logical paradigms from these treatises and manifesting them through AI.

There exists a theoretical consistency among Bharata Muni's equal temperament twenty-two *shrutis*, *Shruti-Nidarshanam* experiment and *Dwi-Vidha Moorchchhana Siddhi* experiment. Readers are advised to refer the relevant appendices for the same.

The word '*Kalaa*' means calculation or computation. GTIM justifies that the art of music in India has computational and logical foundations and it facilitates the aesthetic experience. The major original contribution of the author in this regard is the envisioning and the development of an aural axiomatic system for Indian music. Four axioms, namely, Axiom I of 'self-evident' existence, Axiom II of an octave equivalence, Axiom III of consonances and the Axion IV of equal temperament capture the essence of logical foundations of Indian music.

Many musicologists and researchers are working in the domain of Indian computational musicology but their efforts are limited to applying very specific computational models to Indian music. GTIM has taken up a different approach and arrived at a larger theoretical paradigm that comprehensively addresses wide range of issues and challenges of Indian music. GTIM successfully provides computational and AI-based solutions to these challenges.

GTIM provides formal and mathematical representations of most of the fundamental concepts of Indian music including the concepts such as *Swara, Shruti, Saptaka, Raga, Tala, Bandish* and many others. Formal representations bring in the clarity about musical concepts. The traditional musicians and performers usually shy away from defining these concepts in a very precise way.

Indian music is considered as a *Shastra* or a science. However, the traditional literature on Indian music is mostly prescriptive or descriptive in nature and it is not articulated as a science or a *Shastra*. GTIM articulates and presents Indian music as a science. It tries to unfold and unravel the physics and psycho-physics of Indian music with logical foundations.

Classification of *Ragas* has been an outstanding issue in Indian music. Pandit Venkatamakhin and Pandit Bhatkhande developed their systems for the classification of *Ragas*. The author of this book has great regard for both systems. However, many musicologists and scholars have criticized these systems and found loop holes in these theories. Every attempt has been made in the GTIM paradigm to keep it free from such loop holes. Instead of taking up a normative approach, the GTIM has taken up an evidence-based computational simulation approach to address the problem of characterization of *Raga* and classification of *Ragas*. GTIM has developed '*Nava Gana'* system of *Raga* classification that addresses most of the outstanding issues.

Similarly, theorizing Indian *Talas* was another outstanding problem because currently many diverse systems of *Tala* are prevalent in India. The tradition has great respect for the ancient concepts of *Dasha Pranas* of *Tala* but current practices do not match with them. GTIM has developed the paradigm of '*Nava Gana*' *Talas* that finds a golden mean of all the prevalent *Tala* practices such as *Suladi Sapta Talas* and *Chapu Talas* of Carnatic music, currently popular North Indian *Talas* as well as the ancient *Talas*. *Nava Gana Talas* is a unified theory of Indian *Talas* that is an extension of *Dasha Prana* paradigm of *Tala* in a certain sense.

Apart from formally defining and redefining the prevalent theoretical concepts of Indian music, the GTIM has introduced many new concepts. These concepts include, '*Nitya swaras*', 'Hierarchy of Harmonic Strength of *Swaras* and *Shrutis*', 'Law of Co-existence of *Swaras*', 'Law of Emotive *Swaras*' and many others. These are completely novel concepts. The author of this book has worked on these concepts for many years, tested them, validated them through computer simulations and considers these concepts as paradigms in themselves. Without these concepts, the generative theory of Indian music is not possible.

The *'Bharata Vakya'* of this research is that GTIM is a non-conventional theory in the non-conventional domain of research.

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PART IX
Appendices

Appendix I- *Shruti Nidarshanam* experiment on Bharata Veena

Appendix II- *Gramantara*

Appendix III- AI Systems for Indian Music by Dr. Vinod Vidwans

Appendix IV- *Nava Gana* Classification of Contemporary Ragas

Appendix V- *Nava Gana* Classification of Contemporary Talas

Appendix VI- Computational *Raga* Statistics till May 2023

APPENDIX I

'*Shruti-Nidarshanam*' experiment on *Bharata Veena*

The *Shruti-Nidarshanam* experiment which is also known as a *`Chatuh-Sarana'* experiment, is a unique gift of Bharata Muni to the world of music to demonstrate existence of twenty-two *shrutis*. This experiment is described in the twenty-eighth chapter of Bharata Muni's *Natyashastra* [Brihaspati, 1986, pp. 43-54]. It is not mentioned in any of the earlier treatises on Indian music therefore it is certain that this experiment was invented during Bharata Muni's times. The original creator of this experiment is not known but since it is mentioned in Bharata Muni's *Natyashastra* it is assumed that Bharata Muni himself must have designed it. This experiment is a conclusive proof of equal temperament twenty-two *shrutis*. Following is the description of performing the *Chatuh-Sarana* experiment on two strings on a specially designed *Veena* called *Bharat Veena*. Dr. Vinod Vidwans has designed *Bharat Veen* to empirically verify the *Shruti-Nidarshanam* experiment.

In the original description of the experiment by Bharata Muni, there is a mention of two of the same *Veenas*. In the following description of the experiment, two *Veenas* are represented by two strings in the *`Bharat Veena'*. For the consistency with original description from Bharata Muni's *Natyashastra*, these two strings are termed as two *Veenas*. In the following description where ever there is a mention of *Chala Veena* or *Achala Veena*, it should be understood that they stand for *Chala* string and *Achala* string respectively. As per this experiment, *shrutis* can be demonstrated definitively through an experiment on the *Bharat Veena*. The procedure for this experiment is called the *`Sarana-Chatushtayi'* method. This experiment is very briefly described as follows in a step-by-step manner.

After establishing *swaras*, the *Shruti-Nidarshanam* experiment can be performed on the *Bharat Veena.* Here only salient steps or '*Saranas*' of the experiment are shown below. For the details of this experiment, you can refer to a monograph titled '*The Doctrine of Shrutis in Indian Music*', by the author [Vidwans, V. V., 2016, pp. 62-70]. The four steps of the experiment are as follows. Original photographs of *Bharat Veena* is used in the following description.

First *Sarana*

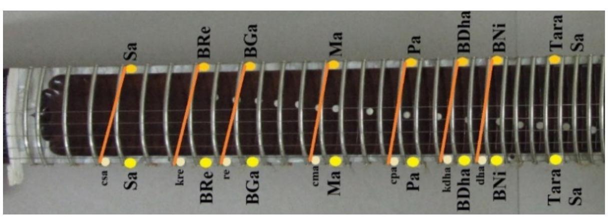
Lower down the *Panchama swara* of *Chala Veena* by one *shruti* (*Pramana shruti*) as discussed in the *Natyashastra* during the description of a *`Pramana Shruti'* [Brihaspati, 1986, pp. 41-42]. So, the *Chala Veena* becomes a *Madhyama Grama Veena*. This is achieved by lowering the *Panchama* of *Chala Veena* such that it will tune with the Bharata's *Rishabha* on the *Achala Veena* with a *Samvad Bhava* of nine-*shruti* distance i.e., *Shadja-Madhyama Bhava*. By this, a *`Pramana shruti'* is demonstrated. Then tune all the rest of the *swaras* of a *Chala Veena* in such a way that keeps the *Panchama's* new position intact, the *Chala Veena* becomes the *Shadja Grama Veena* again. Now the *Chala Veena* is one *shruti* lower than the *Dhruva Veena*. All the *swaras* of *Chala Veena* are one *shruti* lower than all the *swaras* of *Dhruva Veena*.

Swara frequencies of the *Chala Veena* keep shifting at every step in the whole experiment towards the lower side while *Achala Veena swara* frequencies are kept in the original positions. The beauty of the experiment is that at every step one can compare the relative frequencies of each *swara* of the *Chala Veena* with their counter parts on the *Achala Veen*.

For instance, at this first stage, every *swara* of the *Chala Veena* is one *shruti* (*Pramana Shruti*) lower than all the *swaras* of the *Achala Veena*. One can cross-check and understand the aural distance of the *Pramana Shruti*. In other words, one knows the *Pramana Shruti* distance in a definite way.

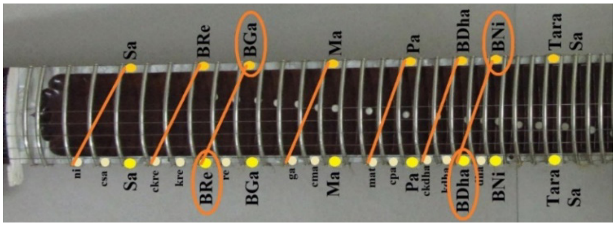
Along with this process, one very important phenomenon is happening and that is, as every *swara* of *Chala Veena* is lowered by one *shruti*, each *swara* is mapped on the one-*shruti* lower position on the *Achala Veena*. As a result, apart from the original *swara/ shruti* positions, seven new positions are generated or mapped on the *Achala Veena*.

Orange lines in the photograph indicate the shifted positions of the original seven *swaras*. Names of the newly mapped *swaras* are written with a smaller font size.



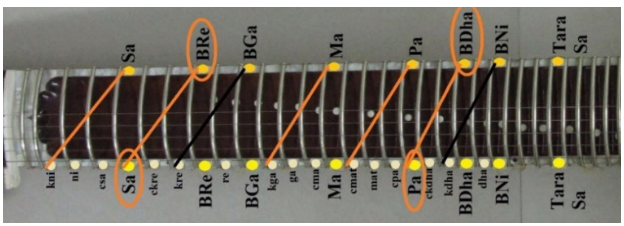
Second *Sarana*

Again, in the same manner lower down the *Chala Veena* by one *shruti* so that *Gandhara* and *Nishada* of *Chala Veena* will be tuned into *Rishabha* and *Dhaivata* of the *Dhruva Veena* respectively because now the *Chala Veena* is two *shrutis* lower than the *Dhruva Veena* [Bharata, p. 20]. As a result, all the *swaras* of *Chala Veena* are now two *shruti* lowered than all the *swaras* of *Achala Veena*.



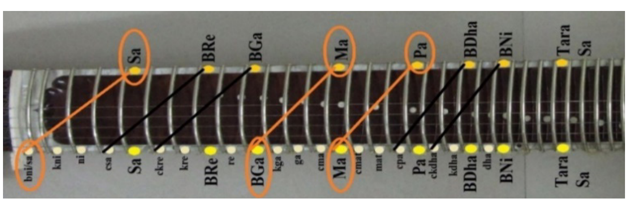
Third *Sarana*

Again, in the same manner lower down the *Chala Veena* by one *shruti* so that *Dhaivata* and *Rishabha* of *Chala Veena* will be tuned (enter) into *Panchama* and *Shadja* of the *Dhruva Veena* respectively because now the *Chala Veena* is three *shrutis* lower than its original position [Bharata, p. 20]. As a result of the mapping process, in the same manner, three more *shrutis* are generated at the end of the third step.



Fourth *Sarana*

Again, in the same manner lower down the *Chala Veena* by one *shruti* so that *Panchama, Madhyama* and *Shadja* of *Chala Veena* will be tuned (enter) into *Madhyama, Gandhara* and *Nishada* of the *Dhruva Veena* respectively because now the *Chala Veena* is four *shrutis* lower than the *Achala Veena* [Bharata, p. 20].



The beauty of the experiment is that at every step *Chala Veena* is lowered by one- *shruti* distance/ interval. Thus, in the first step, *one-shruti* distance/ interval, the second step *two-shruti* distance/ interval, the third step *three-shruti* distance/ interval and in the fourth step the *four-shruti* distance/ interval is demonstrated. At the end of the first step maximum number of *shrutis* i.e., seven new *shrutis* are generated. At the end of the second step slightly less i.e., five new *shrutis* are generated and in the third step, only three new *shrutis* are generated. Thus, in all twenty-two *shrutis* are demonstrated out of which seven *shrutis* (original seven *swaras*) were already there and fifteen *shrutis* are newly generated during the experiment.

The last step does not generate a *shruti*. So, it makes a statement that no newer *shrutis* are possible. If the process continues then the same *shrutis* will keep on mapping one above other but no new *shruti* will be generated. As a result of this *`Shruti Nidarshanam'* experiment twenty-two *shrutis* of two *Gramas* can be experienced or demonstrated.

A very important insight from the experiment is that the *`Shruti-Nidarshanam'* experiment is successful if and only if the twenty-two *shrutis* have the equal temperament. This is the unique condition of the *`Shruti-Nidarshanam'* experiment. If the *shrutis* do not have equal temperament then the mapping will go haywire. Logically and mathematically, this is the only possibility. If the *shrutis* are not equi- distanced then they will not map evenly or they will map on extra positions and generate more *shrutis* or a lesser number of *shrutis* depending on the ratios. *Swara* positions of *Chala Veena* will not map on the seven *swaras* of *Achala Veena* evenly if *shrutis* are not equi-distanced. That is why Bharata puts a strict condition that *Chala Veena* and *Achala Veena*, both should be exactly similar in all respects. Then only this experiment can be conducted. If the *swaras* are fixed in appropriate places then at the end of the experiment it will result in twenty- two equal temperament *shrutis*.

Shruti-Nidarshanam experiment also demonstrates *Samvad Bhavas* or consonances among *swaras* such as ***Sa-Pa, Sa-Ma, BRe-BDha, Bga-Bni, Re- Dha, Ga, Ni*** and so on... This experiment provides the empirical and experimental basis for ***Samvadi Swaras*, *Vivadi Swaras*** and ***Anuvadi Swaras****.* These *Shruti, Swaras, and Samvad-Bhavas* between and among *swaras* lead to many more musical concepts such as ***Jatis, Moorchchhanas***, and ***Taanas***. Ancient music was different from contemporary music. However, these concepts eventually evolved into the system of *Ragas*.

The *`Shruti-Nidarshanam'* experiment is such a profound paradigm that one gets awe-struck by the elegance and precision of the experiment. Only a musical genius having a mathematical and logical bent of mind can design such an experiment. Bharata's paradigm of equal temperament twenty-two *shruti* is not a hypothetical mathematical construct. On the other hand, it was a profound practical paradigm till the times of Abhinavagupta and Sharangadeva i.e., till the thirteenth century A.D. at least. In the contemporary era, this may open up the possibility to explore new musical spaces, new consonances, new dissonances, new melodies and harmonies to take Indian music forward.

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APPENDIX II

Gramantara

(Translating *Shadja Grama* into *Madhyama Grama* and vice-versa)

Any scientific treatise is always consistent in its description of theoretical concepts. Bharata Muni's *Shruti-Nidarshanam* experiment conclusively proves that Bharata's 22 *shrutis* were of equal temperament. Bharata Muni also provides another very important experiment called *Dwi-Vidha Moorchchhana Siddhi*. This experiments also supports that Bharata's 22 *shrutis* were of equal temperament. It means that there exists consistency across various sections of Bharata Muni's *Natyashastra*.

Bharata Muni provides a method to translate the `*Moorchchhanas*' of one *Grama* into the `*Moorchchhanas*' of the other *Grama*. Especially it is easy to do so on a *Veena*. *Moorchchhana* is an ordered sequence of *swaras* in a *Grama*/ *Saptaka*. *Grama* is a group of select *swaras* from the *Saptaka*. *Shadja Grama* and *Madhyama Grama* were two well-established *Gramas* during Bharata Muni's times. Accordingly, he says that in the case of a *Shadja Grama*, the *dvi-shruti Gandhara* needs to be raised to the state of `*Antar Gandhara*' by tuning into *Dhaivata swara*. So instead of *dvi-shruti Gandhara*' the new *Gandhara* will be of four *shrutis*. With this change, the *Shadja Grama* is converted into *Madhyama Grama* and therefore the *Moorchchhanas* of earlier *Shadja Grama* will be translated into the appropriate *Moorchchhanas* of a *Madhyama Grama*. As a result of this transition, names of the *swaras* will change and so *Shadja* will become *Madhyama, Rishabha* will become *Panchama* of *Madhyama Grama, Antar Gandhara* will become *Dhaivata* of *Madhyama Grama*, *Madhyama* will become *Nishada* of *Madhyama Grama*, *Panchama* will become *Shadja* of *Madhyama Grama*, *Dhaivata* will become *Rishabha* of *Madhyama Grama*, and finally *Nishada* will become *Gandhara* of *Madhyama Grama* respectively. Thus, the *Shadja Grama* is converted into *Madhyama Grama*.

Similarly, in the *Madhyama Grama* if *Dhaivata* is reduced by two *shrutis* the whole *Madhyama Grana* is converted into a *Shadja Grama* and thus all the *Moorchchhanas* of *Madhyama Grama* will be translated into the *Moorchchhanas* of *Shadja Grama*. As a result, all the *swaras* of a *Madhyama Grama* such as *Madhyama, Panchama*, new *Dhaivata, Nishada, Shadja, Rishabha*, and *Gandhara* will be redefined as the *swaras* of *Shadja Grama* as *Shadja, Rishabha, Gandhara, Madhyama, Panchama, Dhaivata*, and *Nishada* of *Shadja Grama* respectively. With just one change with the *Dhaivata swara*, the *Madhyama Grama* changes to *Shadja Grama*.

This happens because the relative distances among *shrutis* are preserved. In a *Madhyama Grama* the distance between *Panchama* and *Dhaivata* is of four *shrutis*. When *Dhaivata* is reduced by two *shrutis*, this new *Dhaivata* becomes the *dvi-shruti Gandhara* of a *Shadja Grama*. In the previous case of *Shadja Grama* when *dvi-shruti Gandhara* is raised by two *shrutis* it becomes four *shrutis Gandhara* and is translated or assumed as the four *shruti Dhaivata* of the *Madhyama Grama*. Other remaining *swaras* are mapped respectively because they have the equivalent *shruti* distances. Abhinava Gupta elaborates this phenomenon in his *Abhinava Bharati* as follows.

अत्र वैणिकस्योपदेशार्थमाह द्विविधैकमूर्च्छनाया: षड्जग्रामिक्या द्विविधाया मध्यम ग्रामिक्यो द्वितीयेन प्रकारेण युक्ताया यथासिद्धिर्भवति तथोच्यते |...

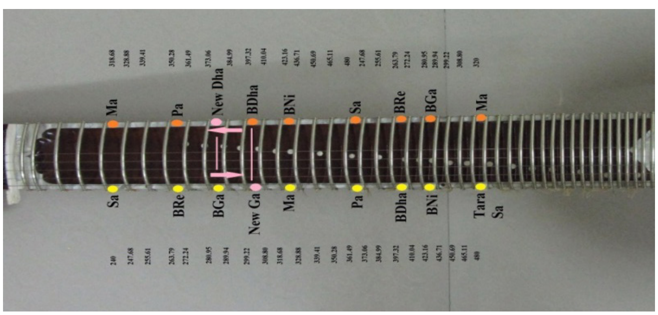
...अत्र हेतुमाह तुल्यश्रुत्यन्तरत्वादिति| संज्ञान्यत्वमित्यनेन प्रयत्नान्तरमत्र न किञ्चिदितिदर्शयति | संज्ञान्तर स्वरे ग्रामे मूर्च्छनायाश्च तुल्यश्रुत्यन्तरत्वं स्पष्टयति अन्तरनिदर्शनमपीति | अपि शब्दाद्वक्तव्यमपि सदित्यर्थ:| श्रुतिनिदर्शनमिति| द्वे वीणे इत्यत्रैव मूर्च्छनानाम् पूर्णावस्थोक्ता |

[Kavi, M. Ramakrishna and Pade, J. S., (Ed.), 1964, p-26]

While commenting on the description from Bharata Muni's *Natyashastra*, Abhinava Gupta points out that Bharata Muni's description of *Dwi-Vidha Moorchchhana Siddhi* is very useful for *Veena* players. Further he comments that it's a strange and equally amazing phenomenon that raising or decreasing just one *swara* has such an impact that one *Grama* is changed into another. This happens because *shruti* distances between the respective *swaras* of one *Grama* are *equivalent* with *swaras* of another *Grama*. With just one change the names of *Gramas*, the names of the *swaras* and the names of *Moorchchhanas* change effortlessly. In the process the `*Antar Gandhara*' *swara* is also recognized with clarity and *shrutis* are demonstrated in a definite way. This method has close correlation with the `*Chatuh Sarana'* experiment. Since `*Taanas*' are based on *Moorchchhanas*, this *Grama* transformation method comes very handy for *Veena* players while performing.

This provides very strong evidence for the fact that Bharata Muni's twenty-two *shrutis* were of equal distance or were of equal temperament. The above-mentioned method of translating one *Grama* to another will not yield the results unless the *shrutis* are of equal temperament. The literature on *shruti* research suggests that there are many proposals for non-equal temperament twenty-two *shrutis*. However, theoretically as well as practically none of them will succeed in satisfying the description of `*Dwi-Vidha Moorchchhana Siddhi*'. For any un-equal temperament proposals, the method will fail. The *swaras* and *shrutis* of one *Grama* will not be translated into the *swaras* and *shrutis* of another *Grama*. In some cases, the *swaras* may be mapped but their internal *shrutis* of the specific *Moorchchhanas* will not be mapped. Internal ratios of respective *shruti*-pairs will not be mapped. In some cases, even the *swaras* will not map. In general, for any non-equal temperament *shruti* proposal, there will be at least two *swaras* along with their *shrutis* of the initial *Grama* that will not be mapped on the desired *swaras* and the *shrutis* of the newly translated/ formed *Grama*. This method is important because it provides a mechanism to convert *Shadja Grama* into the *Madhyama Grama* or vice versa. Apart from that this `*Dwi-Vidha Moorchchhana Siddhi'* method also provides another conclusive evidence for equal-temperament twenty-two *shrutis* of Bharata Muni.

Following diagram provides a graphical description of this experiment for the reference. One can see how *Gramas* are translated in the experiment. The textual description of the experiment is already provided in above paragraphs. Following diagram is for equal temperament *shrutis*.



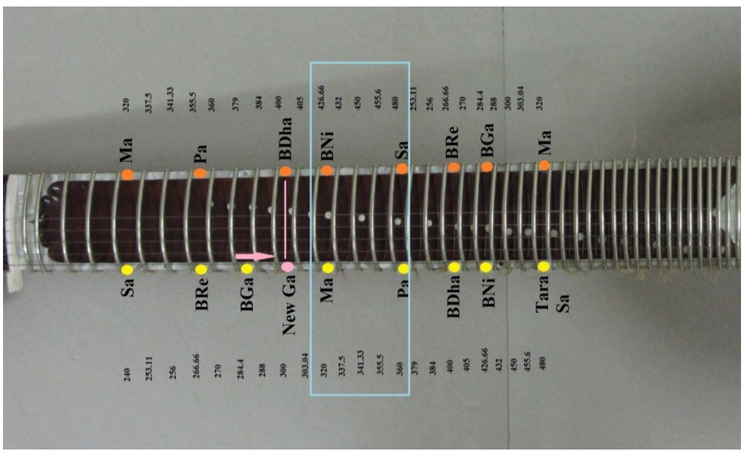
In the above description, Bharata Muni provides a method to translate `*Moorchchhanas*' of one *Grama* into the `*Moorchchhanas*' of the other Grama. Especially it is easy to do so on a *Veena*. Accordingly, he says that in the case of a *Shadja Grama*, the *dvi-shruti Gandhara* needs to be raised to the state of `*Antar*

Gandhara' by tuning into *Dhaivata swara*. So instead of *dvi-shruti Gandhara*' the new *Gandhara* will be of four *shrutis*.

With this change the *Shadja Grama* is converted into *Madhyama Grama* and therefore the *Moorchchhanas* of earlier *Shadja Grama* will be translated into the appropriate *Moorchchhanas* of a *Madhyama Grama*. Other remaining *swaras* are mapped respectively because they have the equivalent *shruti* distances.

Similarly, in the *Madhyama Grama* if *Dhaivata* is reduced by two *shrutis* the whole *Madhyama Grana* is converted into a *Shadja Grama* and thus all the *Moorchchhanas* of *Madhyama Grama* will be translated into the *Moorchchhanas* of *Shadja Grama*. With just one change with the *Dhaivata swara*, the *Madhyama Grama* changes to *Shadja Grama*.

However, in the case of un-equal temperament *shrutis*, as shown in the marked area in the following diagram, the *shruti* distances between *Madhyama* and *Panchama* of *Shadja Grama* and Bharata Muni's *Nishada* & *Tara Shadja* of *Madhyama Grama* do not match appropriately.



Thus, it conclusively proves that Bharata Muni's twenty-two *shrutis* were of equal temperament because otherwise the *Dwi-Vidha Moorchchhana Siddhi* experiment will not succeed.

★ ★ ★

APPENDIX III

AI Systems for Indian Music by Dr. Vinod Vidwans

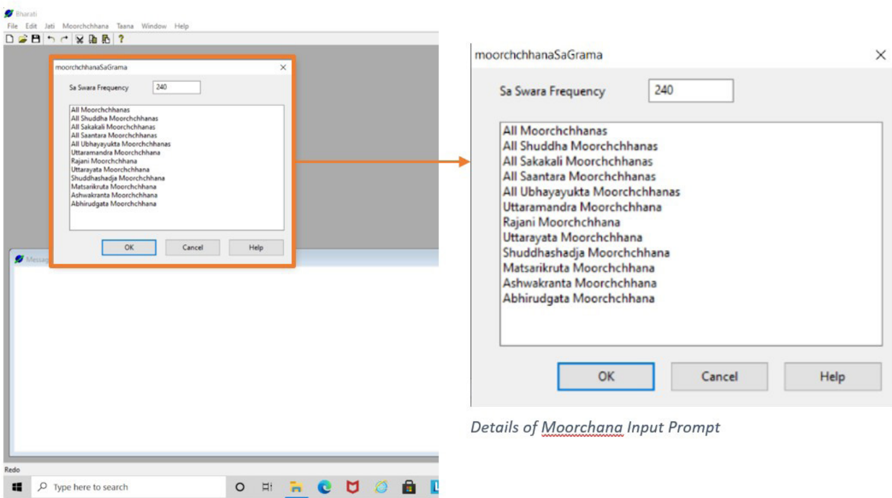
Introduction

The traditional *'Gyana-Samvid'* (Repository of Knowledge) of Indian music can be documented, and preserved in the form of `smart' digital repositories, `smart' books and `smart' systems. The advent of smart technologies and Artificial Intelligence has created many pathways to document, preserve, simulate and even interpret this *'Gyana-Samvid'* innovatively. Artificial Intelligence provides an excellent opportunity to empirically verify and validate the Indic knowledge using technology & simulation on computers. In this sense Indian Music is the ideal candidate for developing expert and 'Smart' Systems for Indian Music that leads to Artificial Musical Intelligence.

In this context Artificially Intelligent Expert Systems for Indian Music called '*Bharati*', '*AI Tala*', '*AIRagaGen*', and '*AI Raga*' have been designed and developed by the author of this book. These smart systems are based on 28th Chapter of Bharata's *Natyashastra* known as 'S*angeetadhyaya'* mainly, and for detailed referencing and fine-tuning *Abhinav Bharati* and *Sangeet Ratnakar* have been referred. *Bharati* system has helped the author to study *Natyashastra* from computational point of view and prepared the right context for the development of GTIM. '*AI Tala*', '*AIRagaGen*', and '*AI Raga*' systems are the manifestations of the GTIM. A brief overview of these systems is presented below.

Bharati System

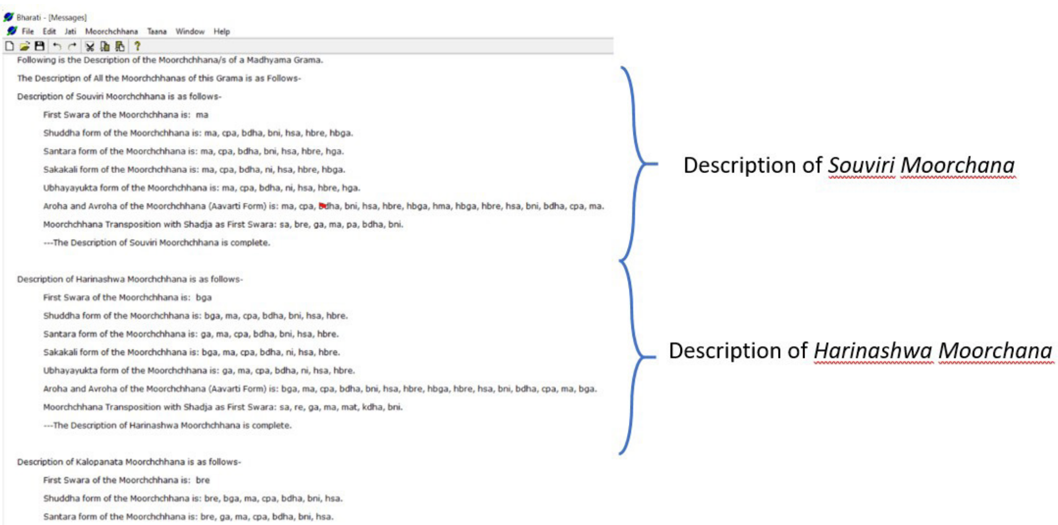
The main objective of the '*Bharati*' system is to show that the theoretical concepts from *'Natyashastra'* and *Sangeet Ratnakar* are logically structured and all *Sutras* can be potentially simulated on computers and to preserve the knowledge treasure. This 'smart' book or expert system provides a textual description of the desired concepts. This smart system has all the core concepts such as Bharata Muni's *swaras,* Bharata Muni's *shrutis, Shadja Grama, Madhyama Grama,* types of *Gandhara Grama, Shuddha Moorchchhanas*, *Santara Moorchchhanas*, *Sakakali Moorchchhanas, Ubhaya Moorchchhanas* and so on. It also has the information about *Sampurna Taanas, Shadava Taanas, Oudava Taanas* as well as information about 18 *Jatis* that include *Shuddha Jatis, Samsargaja Jatis and Sadharanagata Jatis*. In the following image, you can see that the dialog box for *Moorchchhanas* is selected and it shows a long list of entries.



Details of Moorchana Input Prompt

Moorchchhana input prompt

The next image shows more information about the *Moorchchhanas* of *Madhyama Grama* can be obtained



Description of Moorchchhanas of selected Grama

It should be highlighted that there is no static database of these concepts in the system, on the other hand the system only has the core concepts stored in it. Treating the *shlokas* or the *sutras* of *Natyashastra* in the form of codified algorithm, they are operated on the set of core concepts and the necessary computations are performed whenever the user wants some information. As shown in the above images, the user will receive the appropriate response from the *Bharati* system. '*ShrutiGen*' system is also a part of Bharati system that is capable of generating Bharata Muni's ET-22 *shrutis* and also it has a module to simulate the *Shruti- Nidarshanam* experiment.

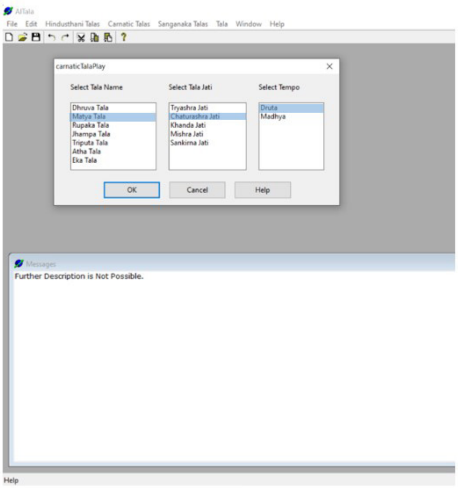
'*AI Tala*' System

The *AI-Tala* system has two important facets. The system can simulate the existing *Talas* of North Indian music and Carnatic music. The other facet of the system is to generate new *Talas*. Description of both the aspects of the *AI-Tala* system are provided below.

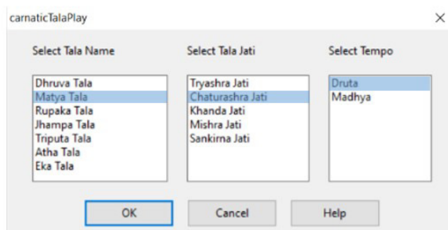
Tala Simulation:

The *AI-Tala* System simulates the *Talas* as well as it can generates new *Talas*. Let us discuss the simulation of *Talas* first. Very important objective of '*AI-Tala* System' is to show that AI can be used as a tool to simulate *Talas* of Indian Music. It demonstrates the creative and aesthetic capabilities of AI. The system generates *Talas* and produces a 'Solo Performance' of about 10 to 15 minutes on the Artificial *Tabla*. This system has all the core concepts and principles of Indian rhythmic cycles called *Talas*. This system is not restricted to *Natyashastra* alone. On the other hand, it is more relevant for contemporary *Talas*. However, the basic concepts and principles of *Tala* are used from the *Natyashastra* and *Sangeet Ratnakara*. '*AI- Tala*' System has the knowledge of *Druta* Laya*, Madhya Laya,* and *Vilambita Laya*. It also deals with *Tryashra* Jatis*, Chaturashra* Jatis*, Khanda* Jatis*, Mishra* Jatis*, Samkirna* Jatis etc. The *AI-Tala* system also possesses the knowledge of *Sapta Talas* of Carnatic music such as *Dhruva Talas, Matya Talas, Roopaka Talas, Jhampa Talas, Triputa Talas, Atha Talas, Eka Talas* and the system can generate all these *Talas* and render them in the form of Tabla solo composition of about 10 to 15 minutes. The audience can listen to this. The popular Carnatic *Talas* called *Chapu Talas* like *Tryashradi Chapu* and *Anuloma- Viloma Krama Chapu* are generated by the *AI-Tala* system and rendered as a performance. Popular *Talas* from North Indian system of music such as *Tritala, Ekatala, Kerava* and many more are generated by the *AI-Tala* system and played on the Tabla for 10 to 15 minutes as a solo performance. The following image shows the interface of the *AI-Tala* system. The dialog box for *Sapta Talas* is seen.

The user can select the name of the *Tala, Jati* of the *Tala* and the 'Tempo' or *Laya* of the *Tala*. Once the user selects the option and clicks on it the *AI-Tala* system generates the appropriate *Tala*.



Tala input prompt



Details of Tala Input Prompt

The above image of the *AI- Tala* screen shows that the user has selected the *Matya Tala* for *Chaturashra Jati* the selected *Laya* is *Druta*. Screen shows all the technical information about the simulated *Tala* as follows.

We will now go through various sections of the output.

Section 1:- Vital details of the *Tala* (Along with some debugging information)

```
The Selected Tala Name is as Follows:
Matya Tala
The Selected Tala Jati is as Follows:
Chaturashra Jati
Tala Tempo for Selected Tala is as Follows:
Druta
All is Well till AngaSamkhya
All is Well till tal_khanda_genpCarnatic
2
All is Well till assign_SamKalTal
[[11,4]]
All is Well till assign_bol
[[[["sam"],["dhin2","dhin2","dha2","dha2"]]],[[["kal"],["tin","tin","ta","ta"]]]]
[[[["sam"],["dhin2","dhin2","dha2","dha2"]]],[[["khaliU"],["ta","tin"]]],[[["kal"],["tin","tin","ta","ta"]]]]
Selected SaptaTala35 is as Follows:
[[[["sam"],["dhin2","dhin2","dha2","dha2"]]],[[["khaliU"],["ta","tin"]]],[[["kal"],["tin","tin","ta","ta"]]]]
Value of Shesh is as Follows:
0
Number of Matras for Selected Tala are as Follows:
10
```

Section 2:- Base *Theka* (Beat/Rhythm) Generation.

```
Theka swaramahat is as Follows:
[[[[["sam"],["dhin2","dhin2","dha2","dha1"]]],[[["khaliU"],["ta","tin"]]],[[["kal"],["tirkitbhari","tay","ta","ta"]]]],[[[["sam"],

Selected Laya is as Follows:
druta

The Base Theka Param is as Follows:

[[[["sam"],["dhin2","dhin2","dha2","dha2"]]],[[["khaliU"],["ta","tin"]]],[[["kal"],["tirkitbhari","tin","ta","ta"]]]]

AngaN Value for Base Tala and Base Theka is as Follows:
2
```

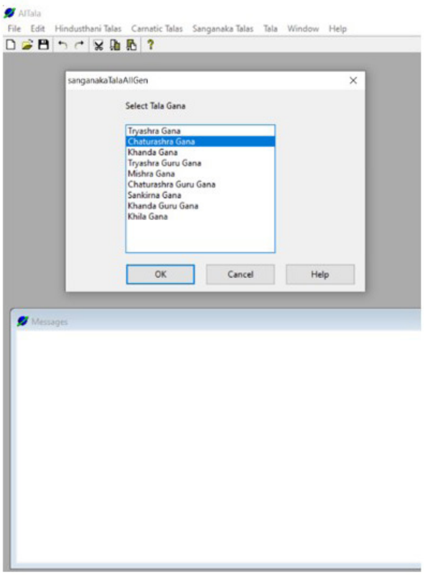
Section 3:- Generation of signature *Anga* etc.

```
NAngaSam Tala is as Follows:
[[[[["khaliU"],["ta","tin"]]],[[["kal"],["tin","tin","ta","ta"]]]],[[[["sam"],["dhin2","dhin2","dha2","dha2"]]

NAngaSam Theka is as Follows:
[[[[["khaliU"],["ta","tin"]]],[[["kal"],["tirkitbhari","tin","ta","ta"]]]],[[[["sam"],["dhin2","dhin2","dha2","c

NAngaSamTala3 is as Follows:

[[[["khaliU"],["ta","tin"]]],[[["kal"],["tin","tin","ta","ta"]]],[[["sam"],["dhin2","dhin2","dha2","dha2"]]]]

NAngaSamTheka1 is as Follows:

[[[["khaliU"],["ta","tin"]]],[[["kal"],["tirkitbhari","tin","ta","ta"]]]]

NAngaSamTheka2 is as Follows:
```

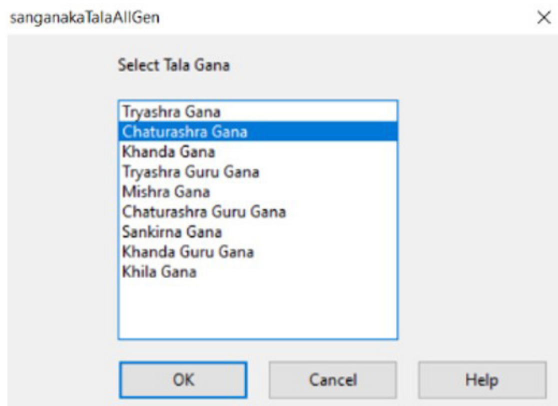
The *AI-Tala* system works as a repository of traditional knowledge. It demonstrates and shows how traditional knowledge can be preserved, smartly processed and applied and how it is made relevant for contemporary musical prentices. This is the strength of digital technology and Artificial Intelligence.

Tala Generation:

Another important objective of '*AI-Tala System*' is to show that AI can be used as a tool to generate existing *Talas* of Indian Music as well as generate new *Talas* for Indian music. The system is capable of generating more than 500 valid *Talas* for Indian music. Following image shows that under the heading 'Samganaka Talas' there is a sub-menu for generating *Talas* called 'Generate *Samganaka Talas'*. Once you click on this menu you get the list of all the *Nava Gana Talas*. Then you choose the *Gana* for generating a *Tala*. As you click on the desired *Gana*, the system starts the process of generating all the valid *Talas* for the selected *Gana*. All the specifications of all the generated *Talas* are displayed on the screen. At the same time a database file is also created on the computer giving all the details of all the generated *Talas*. The details include the computer-generated code name for *Tala, Matra Samkhya, Gana Nama, Prastara* type, *Tala Vajan* and *Vajan Bols* for the *Tala* that can be seen in the third image. Apart from these details, the other details are also generated such as *Anga Samkhya*, catch theme for *Bols* of the *Tala*, *Vibhaga Samkhya*, core *Tala* structure, *Upanga* types if any, and finally *Shesh* that is any extra *Matras*. This information covers all the aspects of a generated *Tala*. With this information even a performer can play a *Tala* on *Tabla* or *Mridangam*. The generated *Talas* can also be played by the system. Currently the system plays a *Tala* on the artificial *Tabla* instrument embedded in the system.

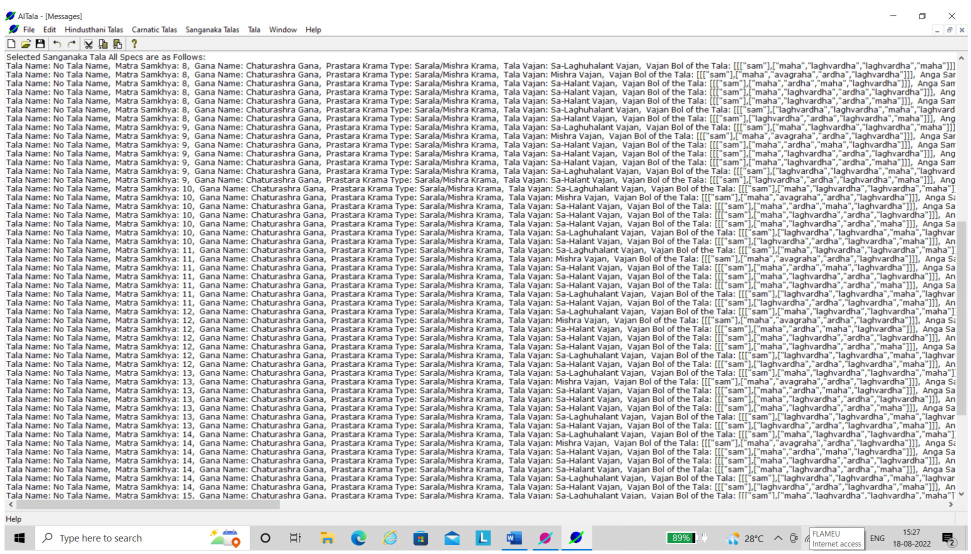


Tala Generation Prompt



Details of Tala Generation Prompt

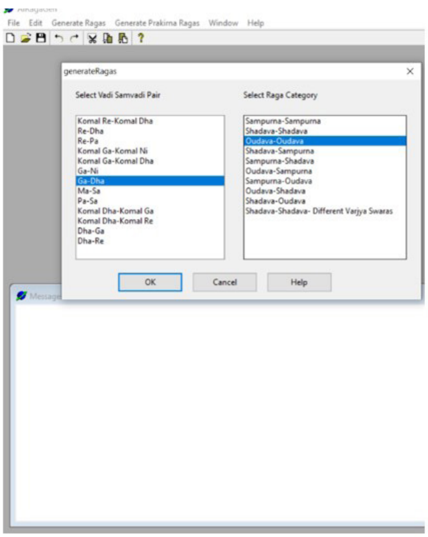
This generates the following output, the output generated contains all the *Talas* of the selected *Gana.*



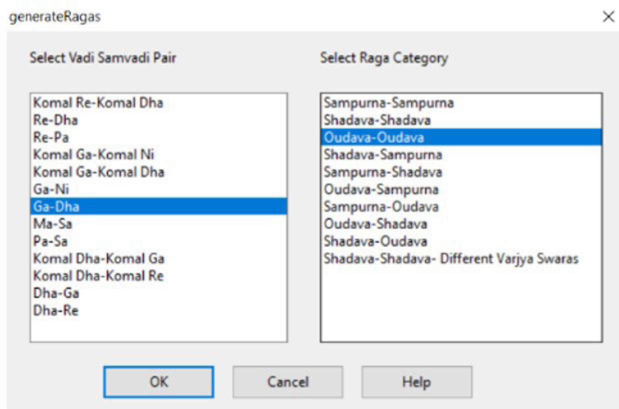
The reams of data required to generate Talas!

'*AI-RagaGen*' System

The main objective of '*AI-RagaGen*' is to show that AI can be used as a tool to generate existing *Ragas* of Indian Music as well as new *Ragas* can be generated for Indian music. The system is capable of generating more than 10,000 valid *Ragas* for Indian music. In the following image it can be seen that in the dialog, the user has selected ‘Ga-Dha’ *swaras* as the *Vadi-Samvadi* pair for generating *Ragas*. It can be seen that the category of the desired *Ragas* is selected as ‘*Oudava-Oudava*’ *Ragas*. With this much information the *AIRagaGen* system generates all possible *Ragas* for the given *Vadi-Samvadi* pair for the particular category of *Ragas*.



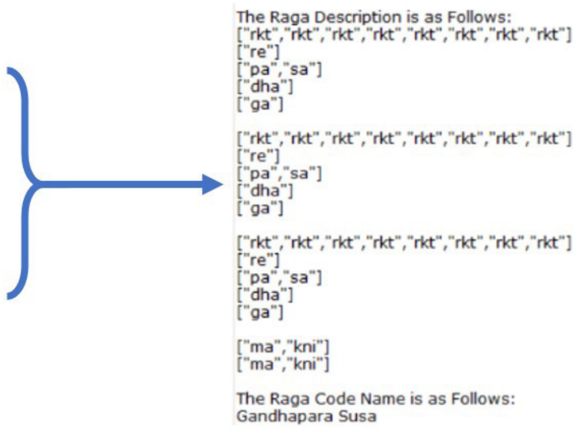
Raga Generation Prompt



Details of Raga Generation Prompt

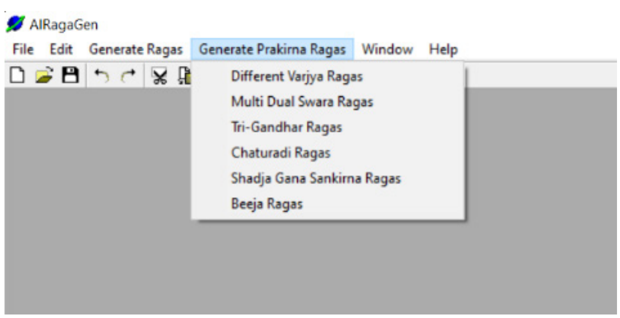
In the next image, the output of the system is displayed. It says ‘*Oudava-Oudava’ Ragas* for the given *Vadi-Samvadi* pair are as follows. The first *Raga* in the generated description happens to be *Raga Bhupa*. The system provides a detailed description of *Raga Bhupa* in the form of lists of *Anya swaras* as a list of ‘rkt’ *swaras*. It means there are no *Anya swaras* for this *Raga*. The next *Anu-Anuvadi swara* list has only one *swara* as ‘re’. Re is the only *Anu-Anuvadi* for the *Raga Bhupa*. The next list is for *Anuvadi swaras* which has *swara* ‘pa’ as primary *Anuvadi* and *swara* ‘sa’ as secondary *Anuvadi*. The next list of *Samvadi swara* shows ‘dha’ *swara* and the fifth list has ‘ga’ as the *Vadi swara*. It also gives the *Arohi* and *Avrohi* lists of *Varjya swaras* that show ‘ma’ and ‘kni’ *swaras*. Finally, it also provides the *Raga* Code Name as ‘*Gandhapara Susa*’ which is a system-generated *Raga* name for *Raga Bhupa*. In the same manner, the description of other possible *Ragas* is generated. For instance, it can be seen in the image that the next *Raga* description is given where there is only one change. It has ‘kre’ as the *Anu-Anuvadi swara*. Other *swaras* are the same. Accordingly, in the end, the system-generated code name for that *Ragas* is ‘*Gandhapaya Susa’*

Generated Raga Data



Details of Generated Raga Data

The above images provide the description about generating regular standard *Ragas* as well as all possible valid *Ragas*. The system also generates '*Prakirna' Ragas* which somehow do not fit in the regular classification of *Ragas*. The following image shows the dialog for *Prakirna Ragas*. A list shows the types of *Prakirna Ragas* which can be generated by the system as 'Different *Varjya swara Ragas'*, 'Multi-dual *swara Ragas*', '*Tri-Gandhar Ragas*', '*Chatuswari Ragas*', and other all possible *Shadja Gana Samkirna Ragas*. The system can also generate all the possible seed *Ragas* which are also called '*Beeja Ragas*'.



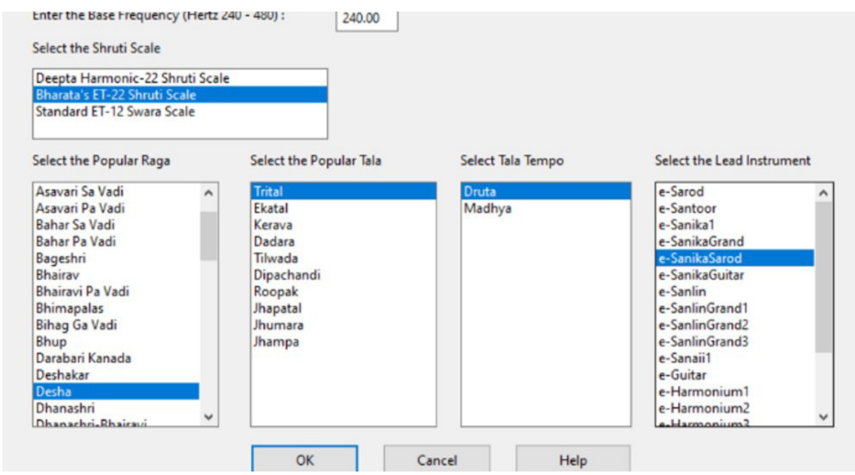
The various types of Prakirna Ragas that can be generated.

AI-RagaGen is a very useful system that generates all possible valid *Ragas* based on the GTIM theory. In this sense *AI-RagaGen* system is the implementation of GTIM theory.

‘*AI-Raga*’ System

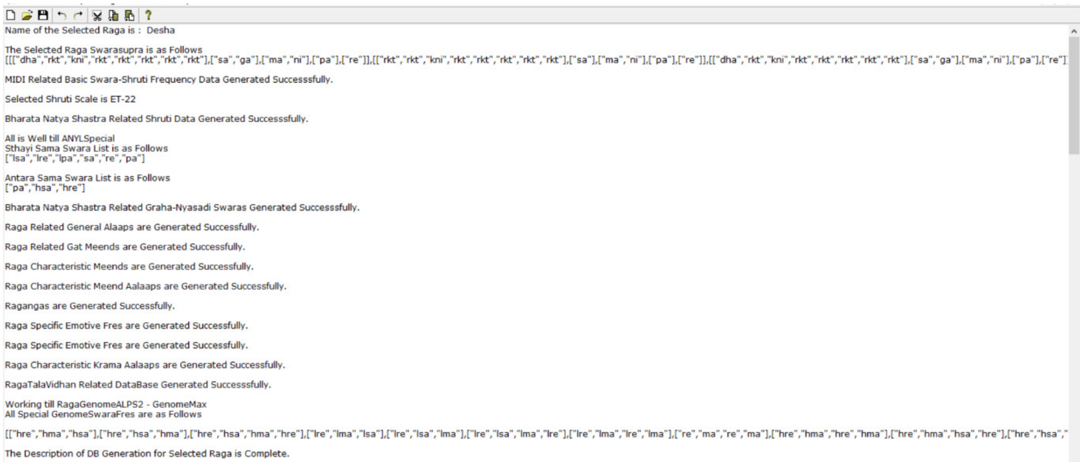
The main objective of ‘*AI-Raga*’ is to show that AI can be used to simulate *Ragas* of Indian Music. In this case AI enters into the realms of human creativity, by composing *Gat/Bandish*. The *AI-Raga* system can generate *Ragas* and composes a *Gat/Bandish* and renders it on artificial instruments accompanied by artificial *Tabla.* This system possesses the knowledge of aforementioned systems viz. *Bharati* and *AI Tala*. It has the encoded knowledge of all the concepts required for generating and playing a *Raga*. These concepts are *Shruti, Vadi, Samvadi, Graha, Nyasa, Shadava, Oudava etc.* and the knowledge of the principles such as the *Shadja-Panchama Bhava, and the Shadja-Madhyama Bhava* from the *Natyashastra* and *Sangeet Ratnakar*. In a sense all the principles of musical logic and inferencing are encoded into the system.

Through simulation of these concepts and detailed computation, the system generates a musical composition on its own in the given *Raga* without any user intervention. In the following image it can be seen that Bharata Muni’s ET-22 Shruti scale is selected by the user and the user has also selected *Raga Desha*. The user wants the system to generate a composition in *Tritala* in *Druta Laya* that is fast tempo. The user has selected the *e-SanikaSarod* as an instrument. This instrument is a digital instrument and generates sound similar to a flute and the sound of an Indian instrument known as ‘*Sarod*’. This instrument does not exist in the real world. The sound of this instrument is created by using digital sound synthesis technology. Once the user clicks, the *AI-Raga* system generates a composition in *Raga Desha*.



Raga Rendition Prompt

In the following image, you can see the output of the AI system - the *Raga* name as *Desha* and all the relevant technical information such as the basic frequency of ‘*Sa’ swara*. Then it says Bharata Muni’s *Natyashastra*-related *Shruti* data is generated. The *AI-Raga* system does not have a fixed database of *swaras* or *Ragas*. Once the name of the *Raga* is given the system generates all the data specific to that *Raga*. The image shows that Bharata Muni's ET-22 *Shruti* scale is chosen by the user. The image also shows that the *Natyashastra* related *Graha-Nyasadi swaras* are generated. The characteristic *Meends, Aalaps, Ragangas* and all required data is generated by the AI system and then a composition or *Gat/ Bandish* is generated and that is played by the computer and the user can listen to it. The final lines of output are displayed below. The output is slightly simplified to increase comprehensibility.



```
Name of the Selected Raga is :  Desha

The Selected Raga Swarasupra is as Follows
[[["dha","rkt","kni","rkt","rkt","rkt","rkt","rkt"],["sa","ga"],["ma","ni"],["pa"],["re"]],[["rkt","rkt","kni","rkt","rkt","rkt","rkt","rkt"],["sa"],["ma","ni"],["pa"],["re"]],[["dha","rkt","kni","rkt","rkt","rkt","rkt","rkt"],["sa","ga"],["ma","ni"],["pa"],["re"]

MIDI Related Basic Swara-Shruti Frequency Data Generated Successsfully.

Selected Shruti Scale is ET-22

Bharata Natya Shastra Related Shruti Data Generated Successsfully.

All is Well till ANYLSpecial
Sthayi Sama Swara List is as Follows
["lsa","lre","lpa","sa","re","pa"]

Antara Sama Swara List is as Follows
["pa","hsa","hre"]

Bharata Natya Shastra Related Graha-Nyasadi Swaras Generated Successsfully.

Raga Related General Alaaps are Generated Successfully.

Raga Related Gat Meends are Generated Successfully.

Raga Characteristic Meends are Generated Successfully.

Raga Characteristic Meend Aalaaps are Generated Successfully.

Ragangas are Generated Successfully.

Raga Specific Emotive Fres are Generated Successfully.

Raga Specific Emotive Fres are Generated Successfully.

Raga Characteristic Krama Aalaaps are Generated Successfully.

RagaTalaVidhan Related DataBase Generated Successsfully.

Working till RagaGenomeALPS2 - GenomeMax
All Special GenomeSwaraFres are as Follows

[["hre","hma","hsa"],["hre","hsa","hma"],["hre","hsa","hma","hre"],["lre","lma","lsa"],["lre","lsa","lma"],["lre","lsa","lma","lre"],["lre","lma","lre","lma"],["re","ma","re","ma"],["hre","hma","hre","hma"],["hre","hma","hsa","hre"],["hre","hsa","

The Description of DB Generation for Selected Raga is Complete.
```

Lines of output indicating the successful completion of processes involved.

One can listen to the outputs of the *AI-Raga* and *AI-Tala* systems at

https://www.youtube.com/channel/UCm_QHdRyO9kcmDqx_OY0KnQ and http://computationalmusic.com/latest_compositions.php

Through simulation of *Ragas*, concepts such as *Shruti, Vadi, Samvadi, Graha, Nyasa, Shadava, Oudava etc.* and principles such as *Shadja-Panchama Bhava, Shadja-Madhyama Bhava* from *Natyashastra* are validated. Through simulation of *Ragas*, we can validate the science of Indian music. An attempt is made to validate principles of music mentioned in *Natyashastra* and *Sangeeta Ratnakara.* The main objective of this research and development of AI systems such as *Bharati, AITala, AIRaga, AIRagaGen* etc. is to show that digitization, computation & AI can be used to document, preserve, interpret and simulate the concepts from Indian music, and take them forward creatively.

This is possible with almost all Indic knowledge systems due to the inherent logical structure present in the *sutra* treatises. By demonstrating the capabilities of AI and it's use in creating Indian classical music, it is asserted that AI has tremendous potential to enable and supplement the study of Indic studies.

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APPENDIX IV

Nava Gana Classification of Contemporary *Ragas*

Introduction

Classification of *Ragas* has been a very important aspect of the theory of *Raga* music. The GTIM envisages a *Nava-Gana* system of classification of *Ragas*. The computational implementation of GTIM provides a sophisticated user-friendly classification system to access all the possible *Ragas*. Following is a partial representation of the computational system in a tabular form focusing on traditional/ known *Ragas*. It is claimed that there exist more than 2000 *Ragas* but after examining those resources it was realized that such claims are not completely correct. Many researchers have compiled the names of the *Ragas* from various sources but detailed description of all the *Ragas* is not available. In many cases, the same *Ragas* are referred to by different names. After scrutiny of the available sources, it was found that authentic detailed information is available only for about 400 *Ragas*. To have some good knowledge about a *Raga* we need the information about *Aroha* and *Avroha*, *Vadi* and *Samvadi swaras*, and *Varjya swaras* if any. This much information is sufficient from a theoretical point of view. Catchphrases and important phrases used in the *Ragas* are also important along with a few compositions in a particular *Raga*. Such information is available for approximately 400 *Ragas* and therefore, it was decided that these *Rags* should be classified as per the *Nava-Gana* system of classification. The above-mentioned *Ragas* are all from North Indian music. The Carnatic music has very good systematic documentation of 72 *Melas* and the *Ragas* that originate from them. However, interestingly the *Vadi-Samvadi swaras* of these *Ragas* are not documented though the performers and practitioners are aware of them. The *Nava-Gana* classification system is based on the *Vadi-Samvadis* of the *Ragas*. In the absence of authentic documentation of *Vadi-Samvadi swaras* it is very difficult to include Carnatic *Ragas* in the following classification system. There is a need of gathering authentic data about *Vadi-Samvadi swaras* of Carnatic *Ragas* so that these *Ragas* can be properly classified under the *Nava-Gana* system. Incidentally, *Ragas* such as *Hamsadhwani* or *Malaya Marutam* have been borrowed in the North Indian music from the Carnatic music. Information about the *Vadi-Samvadis* of such Carnatic *Ragas* is available and therefore such Ragas are included in the following classification. There are many Carnatic *Ragas* such as *Hindola, Mohanam*, and *Sindh Bhairavi* that have their counter-parts in North Indian music as *Malkauns, Bhupali, Bhairavi* respectively. It is possible to co-relate similar *Ragas* from both the styles and find out their *Vadi* and *Samvadi swaras*.

In the following tables there are seven columns for each *Raga* providing the information about the name of the *Raga*, *Vadi swara*, *Samvadi swaras*, *Anuvadi swaras, Anu-Anuvadi swaras, Arohi Varjya swaras,* and *Avrohi Varjya swaras* of the *Ragas.* Information about the *Aroha* and *Avroha* of the *Ragas* is not provided because all the *swaras* are already mentioned and *Arohi and Avrohi Varjya swaras* are also mentioned. So, the information about *Aroha* and *Avroha* is implicitly captured and therefore it is not provided. The author has developed comprehensive scheme for computer generated code name of the *Raga*. However, it is not included in these tables.

In the *Nava-Gana* system of classification, the *Ganas* are structured in the following order. It begins with the *Panchama Gana* and ends with the *Prakirna Gana*. The order is – *Panchama Gana, Madhyama Gana, Gandhara Gana, Rishabha Gana, Komal Gandhara Gana, Komal Rishabha Gana, Dhaivata Gana, Komal Dhaivata Gana* and finally the *Prakirna Gana*. This order is based on the harmonic strength of *Gana-swaras*. The *Shadja Gana* is part of the *Prakirna Gana* because *Shadja swara* is considered as the default *Vadi swara* of all the *Ragas* in the *Prakirna Gana*. Each *Gana* is further sub-divided, based on the number of *swaras* in the *Aroha* and *Avroha* of the *Ragas*, and classified into nine categories as *Sampurna-Sampurna, Shadava-Shadava, Oudava-Oudava, Shadava-Sampurna, Sampurna-Shadava, Oudava-Sampurna, Sampurna- Oudava, Oudava-Shadava* and *Shadava-Oudava* categories. This is the broad hierarchical structure of the *Nava-Gana* classification system of *Ragas*.

To keep the tables simple there are only seven columns in each table. Information about the *Graha, Amsha, Nyasa swaras* and catch-phrases or other important phrases is not included in these table because it is not required from the classification point of view. However, few guidelines are given below to find appropriate *Graha* and *Nyasa swaras* for each *Raga*. Universal set of *Graha swaras*, and *Nyasa swaras* is provided that is very useful to decide the *Graha* and *Nyasa swaras* for a particular *Raga*. Catch-phrases or other important phrases used in the *Raga* can be constructed on this basis. These sets are as follows.

Nitya Graha Swaras = {*Vadi, Samvadi*, Sa, Pa, Ma, KNi, Ni, KGa, Ga}. If any of these *swaras* and their lower octave and higher octave versions are there in the *Raga* then they can be used as *Graha swaras* for the *Raga*.

Nitya Nyasa Swaras = {*Vadi, Samvadi*, Sa, Pa, Ma}. If any of these *swaras* and their lower octave and higher octave versions are there in the *Raga* then they can be used as *Nyasa swaras* in the *Raga*. These swaras can also be used as *Vinyasa, Apanyasa* and *Sannyasa*.

Nitya Amsha Swaras = {*Vadi, Samvadi, Anuvadis*, Sa, Pa, Ma}. This set of *Amsha swaras* is very important. *Vadi*, Sa and Pa are the real Nitya *Amsha swaras*. Other members of this set can become *Amsha swaras* if they fulfil the following conditions. *Samvadi* or *Anuvadi* can become an *Amsha swara* if their harmonic strength is less than the *Vadi swara*. Ma can become *Amsha swara* in the absence of Pa *swara* or if Pa is *Ardha Varjya swara*.

A few pairs of swaras can be used for *Meend* or glides. Sa - *Vadi*, Pa - *Vadi*, *Samvadi* - *Vadi,* and *Anuvadi* - *Vadi* are some of the characteristic *Meends* or glides that can be used for a particular *Raga*. Traditionally such glides are called '*Aantar Marg*'.

Raga always has only one *Vadi swara* so in the column of a *Vadi swara* there is only one *Vadi swara* mentioned. However, there is an exception. In some cases, if *Vadi* is Ma, then there can be Mat (*Teevra Madhyama*) along with it. But *Raga* can have two or more *Samvadi, Anuvadi* or *Anu-Anuvadis swaras*. In the respective columns all the *Samvadis, Anuvadis and Anu-Anuvadis* are mentioned. In all such cases following norms should be used to decide about the primary and secondary status of these *swaras*. In all such cases four norms or the rules of thumb should be followed. They are described as follows.

If a choice has to be made between the *Nitya swaras* then the law of harmonic strength for *Nitya swaras* is to be followed. The law is represented as : Pa > Ma > Sa. It means among *Nitya swaras* Pa is the strongest and Sa is the weakest. This is due to the over prevalence of Sa *swara* being the tonic. *Tanapura* harmonic context is also responsible for this order.

If a choice is to be made between a *Nitya swara* and a non-*Nitya swara* then the *Nitya swara* is ascribed the primary status and the other *swara* is considered as a secondary *swara*. In the case of *Samvadis* the primary *swara* is called main *Samvadi* and the secondary *swara* is called *Anya Samvadi*.

If a choice is to be made between two non-*Nitya swaras* then the *swara* that has *Shadja-Panchama Bhava* relationship with the *Vadi swara* is chosen as the primary *swara* and the other *swara* becomes the secondary *swara*. The last norm is based on the harmonic strength of *swaras*. Accordingly, harmonically stronger *swara* is considered as the primary *swara* and the other *swara* is treated as secondary *swara*. The law harmonic strength is briefly mentioned below for standard 12 *swaras*. All the other *swaras/ shrutis* are weaker than the following swaras.

Sa > Pa > Ma > Ga >Re > KGa > KRe > Dha > KDha > Ni > KNi > Mat

This order is important. The left most *swara* Sa is harmonically strongest *swara* while the right most Mat is harmonically weakest *swara*.

With the help of these norms if there are two *Samvadi swaras then the strongest becomes the main* Samvadi and the other becomes the *Anya Samvadi swara* for *Raga*. Similarly, if there are two *Anuvadi swaras* then the strongest becomes the primary *Anuvadi* and the other *swara* becomes the secondary *Anuvadi swara*. For *Anu-Anuvadis*, if there are two *Anu-Anuvadi swaras* then the strongest becomes the primary *Anu-Anuvadi* and the other *swara* becomes the secondary *Anu-Anuvadi swara*. If there are two *swara*-forms of the *swara* then they should be treated as one *swara* and the regular or sharp form of the *swara* is normally used in the *Aroha* and the flat version is used in the *Avroha*.

In certain cases, *swaras* are shown inside the brackets like (‘Mat’). It means that the *swara* is ‘*Durbala*’ or weak in the *Raga* or it is used in a *Vakra* fashion. If it is shown in the column of *Varjya swaras* then it means that the *swara* is *Varjya* but it can be used rarely or occasionally.

There are some *Ragas* that have same set of swaras and the same *Vadi-Samvadis* also. As per the *Nava-Gana* system they are treated as same *Ragas*. However, traditionally in some cases they are treated as different *Ragas* due to some minor variations or some other subtle specificities. Such *Ragas* are shown separately in the following tables just to preserve the traditional practices. However, as per the *Nava-Gana* system they are one and the same *Raga*. At certain other places there are two different *Ragas* by the same name as per the tradition. In such cases they are shown differently by calling them RagaName-1 and RagaName-2 etc. along with some specific information.

For some categories, there are no traditional *Ragas* available. In such cases it is mentioned that there are no existing *Ragas* for this category. However, there can be a computationally generated *Raga* in that category.

The above information and the norms are helpful to understand the following tabular classification for approximately 400 traditional *Ragas* as per the *Nava-Gana* system.

Following tabular representation is based on the book titled ‘*Shruti Vilas*’ (Hindi), by Kashikar S. V., Publisher: Samskara Prakashan, Mumbai, India, 2000. The *Nava-Gana* classification of traditional *Ragas* is as follows.

Panchama Gana Ragas

Panchama Gana: Sampurna-Sampurna Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Anand Bhairavi	Pa	Sa, Re	KGa, KNi	Ma, KDha	Nil	Nil
Bahar Malhar	Pa	Sa, Re	KGa, KNi, Ni	Ma, Dha	Nil	Nil
Bans Kanada	Pa	Sa, Re	KGa, KNi (Ni)	Ma, KDha, (Dha)	Nil	Nil
Bhairavi	Pa	Sa, KRe	KGa, KNi	Ma, KDha	Nil	Nil
Bhankhar	Pa	Sa, KRe	Ga, Ni	Ma, Mat, Dha	Nil	Nil
Chhaya	Pa	Sa, Re	Ga, Ni, (KNi)	(Ma), Dha	Nil	Nil
Chhaya Malhar	Pa	Sa, Re	Ga, Ni, KNi	Ma, Dha	Nil	Nil
Chhaya Tilak	Pa	Sa, Re	Ga, Ni, (KNi)	Ma, Dha	Nil	Nil
Chhayanat	Pa	Sa, Re	Ga, Ni, KNi	Ma, Mat, Dha	Nil	Nil
Chhayanat	Pa	Sa, Re	Ga, Ni, KNi	Ma, Mat, Dha	Nil	Nil
Desi Kanada or Revati Kanada	Pa	Sa, Re	KGa, KNi (Ni)	Ma, Dha	Nil	Nil
Gara	Pa	Sa, Re	Ga, KGa, Ni, KNi	Ma, Dha	Nil	Nil
Gaud	Pa	Sa, Re	KGa, KNi, Ni	Ma, Dha	Nil	Nil
Gunakali (Bilawal Type)	Pa	Sa, Re	Ga, Ni	Ma, Dha	Nil, (Ma), (Ni)	Nil
Hijaj Bhairav-2	Pa	Sa, Re, KRe	Ga, Ni	Ma, KDha	Nil	Nil
Jangala	Pa	Sa, Re	Ga, KGa, Ni, KNi	Ma, Dha, KDha	Nil	Nil
Jangala (Aasavari Type)	Pa	Sa, Re	Ga, KGa, KNi	Ma, KDha, (Dha)	Nil	Nil
Jangala (Bhairav Type)	Pa	Sa, KRe	Ga, Ni	Ma, (Dha), KDha	Nil	Nil

Table to be continued

Jounpuri Bhairav (Prakirna)	Pa	Sa, Re, KRe	Ga, KGa, Ni, KNi	Ma, KDha	Nil	Nil
Kafi	Pa	Sa, Re	KGa, KNi	Ma, Dha	Nil	Nil
Kafi Kanada 1	Pa	Sa, Re	KGa, KNi (Ni)	Ma, Dha	Nil	Nil
Kafi Kanada 2	Pa	Sa, Re	KGa, KNi (Ni)	Ma, KDha	Nil	Nil
Kalingada	Pa	Sa, KRe	Ga, Ni	Ma, KDha	Nil	Nil
Kamod	Pa	Sa, Re	Ga, Ni, KNi	Ma, Mat, Dha	Nil	Nil
Kanada Malhar	Pa	Sa, Re	KGa, Ni, KNi	Ma, Dha, KDha	Nil	Nil
Kolu Malhar	Pa	Sa, Re, KRe	Ga, KNi	Ma, KDha	Nil	Nil
Mand	Pa	Sa, Re	Ga, Ni	Ma, Dha	Nil (Re), (Dha)	Nil
Multani Shree	Pa	Sa, KRe	Ga, KGa, Ni	Mat, KDha	Nil	Nil
Nat Kamod or Kamod Nat	Pa	Sa, Re	Ga, Ni, (KNi)	Ma, (Mat), Dha	Nil	Nil
Paraj	Pa	Sa, KRe	Ga, Ni	Ma, Mat, KDha	Nil	Nil
Pat Manjiri-1 (Bila-wal Type)	Pa	Sa, Re	Ga, Ni	Ma, Dha	Nil	Nil
Pat Manjiri-2 (Kafi Type)	Pa	Sa, Re	KGa, KNi	Ma, Dha	Nil (KGa), (Dha)	Nil
Puriya Dhanashri	Pa	Sa, KRe	Ga, Ni	Mat, KDha	Nil	Nil
Ramakali	Pa	Sa, KRe	Ga, Ni, KNi	Ma, Mat, KDha	Nil	Nil
Rayasa Kanada	Pa	Sa, Re	KGa, KNi	Ma, Dha	Nil	Nil
Saraparada	Pa	Sa, Re	Ga, Ni, (KNi)	Ma, Dha	Nil	Nil

Table to be continued

Saraparada	Pa	Sa, Re	Ga, Ni	Ma, Dha	Nil	Nil
Savani Kalyan	Pa	Sa, Re	Ga, Ni	Ma, Dha	Nil, (Ma), (Ni)	Nil
Shahana	Pa	Sa, Re	KGa, KNi	Ma, Dha	Nil	Nil
Shahana 2	Pa	Sa, Re	KGa, KNi, Ni	Ma, Dha	Nil	Nil
Shahana 3	Pa	Sa, Re	KGa, Ga, KNi, Ni	Ma, Dha	Nil	Nil
Shri Tanka (Tanki)	Pa	Sa, KRe	Ga, Ni	(Ma), (Mat), KDha	Nil	Nil
Sindh Kafi	Pa	Sa, Re	KGa, Ga, KNi, Ni	Ma, Dha	Nil	Nil
Vasant Bhairav	Pa	Sa, KRe	Ga, Ni	Ma, Mat, KDha	Nil	Nil
Vasant Mukhari	Pa	Sa, KRe	Ga, KNi	Ma, KDha	Nil (KRe)	Nil
Vinay Kanada	Pa	Sa, Re	Ga, KGa, Ni, KNi	Ma, Dha	Nil	Nil
Yamani Bilawal	Pa	Sa, Re	Ga, Ni	Ma, Mat, Dha	Nil	Nil
Yogashree	Pa	Sa, KRe	Ga, Ni	Mat, Dha	Nil	Nil

Panchama Gana: Shadava-Shadava Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Adana	Pa	Sa, Re	Ni, KNi, KGa	Ma, KDha	KGa	KDha
Chanchalas Malhar	Pa	Sa, Re	KGa, Ni, KNi	Ma	Dha	Dha
Chandra Kalyan	Pa	Sa, Re	Ni	Mat, KDha	Ga	Ga
Deshakhya	Pa	Sa, Re	KGa, KNi	Ma	Dha	Dha
Devsakh	Pa	Sa, Re	KGa, KNi (Ni)	Ma	Dha	Dha

Table to be continued

Devsakh 2	Pa	Sa, (Re)	KGa, KNi (Ni)	Ma	Dha	Dha
Dipak- 2 (Poorvi Type)	Pa	Sa, KRe	Ga, Ni	Mat, KDha	KRe	Ni
Gopi Vasant	Pa	Sa	KGa, KNi	Ma, KDha	Re	Re
Hamsa Manjiri	Pa	Sa, Re	KNi	Ma, Dha	Ga	Ga
Koumari	Pa	Sa, KRe	Ga, Ni	Mat	Dha	Dha
Malaya Marutam	Pa	Sa, KRe	Ga, KNi	Dha	Ma	Ma
Mangal Bhairav- 3	Pa	Sa, KRe	Ga	Ma, Dha	Ni	Ni
Palasi	Pa	Sa, Re	KGa, Ni, KNi	Ma	Dha	Dha
Sagera (Ahiravati)	Pa	Sa, KRe	GA, KNi	Dha	Ma	Ma
Salagavarali	Pa	Sa, KRe	KGa, KNi	Dha	Ma (KRe)	Ma
Saraswati	Pa	Sa, Re	KNi	Mat, Dha	Ga	Ga
Shubha Kalyan (Jana Sammohini)	Pa	Sa, Re	Ga, KNi	Dha	Ma	Ma
Sudharai	Pa	Sa, Re	KGa, Ni, KNi	Ma	Dha	Dha
Suha Sudharai	Pa	Sa, Re	KGa, Ni, KNi	Ma	Dha	Dha

Panchama Gana: Oudava-Oudava Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anu-vadi***	***Arohi Varjya***	***Avrohi Varjya***
Desha Gaud	Pa	Sa, KRe	Ni	Ma, KDha	Ga, Ma	Ga, Ma
Dhani Kauns (Pa Vadi)	Pa	Sa	KGa, KNi	Ma	Re, Dha	Re, Dha
Jait	Pa	Sa, KRe	Ga	Dha	Ma, Ni	Ma, Ni
Jait Kalyan	Pa	Sa, Re	Ga	Dha	Ma, Ni	Ma, Ni

Table to be continued

Jog	Pa	Sa	Ga, KGa, Ni	Ma	Re, Dha	Re, Dha
Kalavati	Pa	Sa	Ga, KNi	Dha	Re, Ma	Re, Ma
Madhu Kauns	Pa	Sa	KGa, KNi	Mat	Re, Dha	Re, Dha
Malashri	Pa	Sa	Ga, Ni	Mat	Re, Dha	Re, Dha
Megh Malhar (Shuddha Malhar)	Pa	Sa, Re	Ni, KNi	Ma	Ga, Dha	Ga, Dha
Pahadi	Pa	Sa, Re	Ga	Dha	Ma, Ni	Ma, Ni
Pat Ranjani	Pa	Sa	KGa, KNi	Ma	Re, Dha	Re, Dha
Reva	Pa	Sa, KRe	Ga	KDha	Ma, Ni	Ma, Ni
Shiva Ranjani	Pa	Sa, Re	KGa	Dha	Ma, Ni	Ma, Ni
Vaijayanti	Pa	Sa, Re	Ni	Mat	Ga, Dha	Ga, Dha
Yashovati Sarang	Pa	Sa, Re	Ni	Ma, Dha	Ga, Dha	Ga, Ni
Zilaph (Bhairav Type)	Pa	Sa, (KRe)	Ga, (KNi)	Ma, KDha	Re, Ni	Re, Ni

Panchama Gana: Shadava-Sampurnas Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Aanandi	Pa	Sa, Re	Ga, Ni	Ma, Mat, Dha	Re	Nil
Barava	Pa	Sa, Re	KGa, Ni, KNi	Ma, Dha	KGa	Nil
Bhavasakh	Pa	Sa, Re	KGa, KNi (Ni)	Ma, Dha	Dha	Nil
Chaiti Gauri	Pa	Sa, KRe	Ga, Ni	Ma, Mat, KDha	Ga	Nil
Devgiri Bilawal	Pa	Sa, Re	Ga, Ni, (KNi)	Ma, Dha	Ma	Nil, (Ga), (Dha)
Jana Ranjani	Pa	Sa, Re	Ga, Ni	Ma, Dha	Dha	Nil, (Ni)
Komal Desi	Pa	Sa, Re, KRe	KGa, KNi	Ma, KDha	KGa	Nil

Table to be continued

Mand Bhairav	Pa	Sa, KRe	Ga, Ni	Ma, Dha	KRe	Nil
Mudrik Kanada	Pa	Sa, Re	KGa, KNi (Ni)	Ma, Dha	Dha	Nil
Mudrik Kanada Type 2	Pa	Sa, (Re)	KGa, KNi (Ni)	Ma, Dha	Dha, (Re)	Nil
Nand	Pa	Sa, Re	Ga, Ni	Ma, Mat, Dha	Re	Nil
Nand Bhairav	Pa	Sa, KRe	Ga, Ni	Ma, Mat, Dha	KRe	Nil
Panjabi Barava	Pa	Sa, Re	Ga, Ni, KNi	Ma, Dha	Ga	Nil
Pat Bihag	Pa	Sa, Re	Ga, Ni, KNi	Ma, Dha	Dha	Nil
Shahana Kanada	Pa	Sa, Re	KGa, KNi	Ma, Dha	Dha	Nil
Shri Tank	Pa	Sa, KRe	Ga, Ni	Mat, KDha	Mat	Nil
Sudharai Type1	Pa	Sa, Re	KGa, Ni, KNi	Ma, Dha	Dha	Nil

Panchama Gana: Sampurna-Shadava Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Hind Ranjani	Pa	Sa, KRe	Ga, KNi	Ma, Dha	Nil	KRe

Panchama Gana: Oudava-Sampurna Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Bheem	Pa	Sa, Re	Ga, KGa, KNi	Ma, Dha	Re, Dha	Nil
Bihad Bhairav	Pa	Sa, KRe	Ga, KGa, Ni, KNi	Ma, KDha	Ga, Ni	Nil
Champakali	Pa	Sa, Re	Ga, KNi	Mat, Dha	Re, Dha	Nil
Charju Ki Malhar	Pa	Sa, Re	KGa, Ni, KNi	Ma, Dha	KGa, Dha	Nil
Desi (Deshi Todi)	Pa	Sa, Re	KGa, KNi	Ma, Dha, KDha	KGa, KDha	Nil

Table to be continued

Dhanashri (Bhairavi)	Pa	Sa, KRe	KGa, KNi	Ma, KDha	KRe, KDha	Nil
Dhanashri (Kafi)	Pa	Sa, Re	KGa, KNi	Ma, Dha	Re, Dha	Nil
Gou Ranjani	Pa	Sa, KRe	KGa, Ni	Mat, KDha	KRe, KDha	Nil
Hamsa Kinkini (Dhanashri Type)	Pa	Sa, Re	Ga, KGa, Ni, KNi	Ma, Dha	Re, Dha	Nil
Karnataki	Pa	Sa, Re	KGa, Ni	Ma, Dha, KDha	Ma, Ni	Nil
Madhuvanti (Ambika)	Pa	Sa, Re	KGa, Ni, KNi	Mat, Dha	Re, Dha	Nil
Mulatani	Pa	Sa, KRe	Ga, Ni	Mat, KDha	KRe, KDha	Nil
Mulatani Dhanashree	Pa	Sa, KRe	KGa, Ni, KNi	Ma, Mat, KDha	KRe, KDha	Nil
Pata Deep	Pa	Sa, Re	KGa, Ni	Ma, Dha	Re, Dha	Nil
Rahi	Pa	Sa, Re	Ga, Ni, KNi	Ma, Dha	Ga, Ni, KNi	Nil
Revati (Kanada)	Pa	Sa, Re	KGa, KNi	Ma, Dha	KGa, KNi	Nil
Roopa Manjiri Malhar	Pa	Sa, Re	Ga, KGa, Ni, KNi	Ma, Dha	Ga, Dha	Nil
Saindhavi (Sin-dura)	Pa	Sa, Re	KGa, KNi	Ma, Dha	KGa, KNi	Nil
Savani (Bihag Type)	Pa	Sa, Re	Ga, Ni	Ma, Dha	Re, Dha	Nil
Saveri	Pa	Sa, KRe	Ga, Ni	Ma, KDha	Ga, Ni	Nil
Sindhu Bahar	Pa	Sa, Re	KGa, KNi, Ni	Ma, Dha	KGa, KNi, Ni	Nil
Sindura Asavari	Pa	Sa, Re	KGa, KNi	Ma, Dha, KDha	KGa, KNi	Nil

Panchama Gana: Sampurna-Oudava Ragas

There are no existing *Ragas* for this category.

Panchama Gana: Oudava-Shadava Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Hem Kalyan	Pa	Sa, Re	Ga	Ma, Dha	Ni, (Dha)	Ni
Kalashri (Pa Vadi)	Pa	Sa, Re	Ga, KNi	Dha	Ma, Re	Ma
Kalavati Kalyan	Pa	Sa, Re	Ga, KNi	Dha	Ma, Re	Ma
Pat Malhar	Pa	Sa, Re	KNi	Ma, Dha	Ga, Dha	Ga
Sarasvati	Pa	Sa, Re	Ga, KNi	Mat, Dha	Ga, KNi	Ga

Panchama Gana: Shadava-Oudava Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Shankara	Pa	Sa	Ga, Ni	Mat, Dha	Re	Re, Mat

Madhyama Gana Ragas

Madhyama Gana: Sampurna-Sampurna Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Araj	Ma, Mat	Sa, KNi, Ni	KRe, Dha	Pa, Ga	Nil	Nil
Ahi Mohini	Ma	Sa, KNi	Re, Dha, KDha	Pa, Ga, KGa	Nil	Nil
Ahir Bhairav	Ma	Sa, KNi	KRe, Dha	Pa, Ga	Nil	Nil
Anand Bhairav	Ma	Sa, Ni	KRe, Dha	Pa, Ga	Nil	Nil
Bageshri Kanada	Ma	Sa, KNi, (Ni)	Re, Dha	Pa, KGa	Nil	Nil
Bahar Sarang	Ma	Sa, KNi, Ni	Re, Dha	Pa, KGa	Nil	Nil
Bhairavi (Ma Vadi)	Ma	Sa, KNi	KRe, KDha	Pa, KGa	Nil	Nil
Bhatiyar	Ma, Mat	Sa, Ni	KRe, Dha	Pa, Ga	Nil	Nil
Champak	Ma	Sa, Ni, KNi	Re, Dha	Pa, Ga	Nil	Nil
Charukeshi	Ma	Sa, KNi	Re, KDha	Pa, Ga	Nil	Nil

Table to be continued

Devata Bhairav	Ma	Sa, Ni	KRe, KDha	Pa, Ga, KGa	Nil	Nil
Gara Kanada	Ma	Sa, KNi, Ni	Re, Dha	Pa, Ga, KGa	Nil	Nil
Gaud Malhar-1	Ma	Sa, KNi, (Ni)	Re, Dha	Pa, Ga	Nil	Nil
Gaud Malhar-2	Ma	Sa, KNi, (Ni)	Re, Dha	Pa, KGa	Nil	Nil
Gunji Kanada	Ma	Sa, KNi	Re, KDha	Pa, KGa, Ga	Nil	Nil
Hameer Nat	Ma, Mat	Sa, Ni	Re, Dha	Pa, Ga	Nil	Nil
Hijaj	Ma	Sa, KNi	Re, KRe, KDha	Pa, Ga,	Nil	Nil
Hijaj Bhairav	Ma	Sa, KNi	(KRe), KDha	Pa, (Ga),	Nil	Nil
Kabeer Bhairav-1	Ma	Sa, Ni	Re, KRe, KDha	Pa, Ga, KGa	Nil	Nil
Kanada Bahar	Ma	Sa, KNi, Ni	Re, KDha, Dha	Pa, KGa	Nil	Nil
Kausi Kanada	Ma	Sa, KNi	Re, Dha	Pa, KGa	Nil	Nil
Kausi Kanada (Malkauns)	Ma	Sa, KNi	Re, KDha	Pa, KGa	Nil	Nil
Kausi Kanada 3	Ma	Sa, KNi	Re, KDha	Pa, KGa	(Re), (Dha), Nil	Nil
Kedar Bahar	Ma, Mat	Sa, Ni, KNi	Re, Dha	Pa, KGa	Nil	Nil
Kedar Nat	Ma, Mat	Sa, Ni, (KNi)	Re, Dha	Pa, Ga	Nil	Nil
Khamaji Kanada	Ma	Sa, KNi, Ni	Re, Dha	Pa, Ga, KGa	Nil (Re)	Nil
Kukubh Bilawal	Ma	Sa, Ni, KNi	Re, Dha	Pa, Ga	Nil	Nil
Lachari Todi	Ma	Sa, KNi, Ni	Re, KDha, Dha	Pa, KGa, Ga	Nil	Nil
Lalit Kali	Ma, Mat	Sa, Ni, KNi	KRe, KDha	Pa, Ga	Nil	Nil
Lalita Gauri (Lalit Bhatiyar)	Ma, Mat	Sa, Ni	KRe, Dha, KDha	Pa, Ga	Nil	Nil
Mangal Bhairav	Ma	Sa, Ni	KRe, KDha	Pa, Ga	Nil	Nil
Nat Bhairav	Ma	Sa, Ni	Re, KDha	Pa, Ga,	Nil	Nil
Nat Bilawal	Ma	Sa, Ni, KNi	Re, Dha	Pa, Ga	Nil (Re)	Nil
Nat Malhar	Ma	Sa, KNi, Ni	Re, Dha	Pa, Ga, KGa	Nil	Nil
Nat Malhar (Type 2)	Ma	Sa, KNi	Re, Dha	Pa, Ga, KGa	Nil	Nil
Nat Narayan	Ma	Sa, Ni	Re, Dha	Pa, Ga	Nil, (Ni)	Nil, (Ga)

Table to be continued

Nayaki Malhar	Ma	Sa, KNi, Ni	Re, Dha	Pa, KGa	Nil	Nil
Prabhat	Ma, Mat	Sa, Ni	KRe, KDha	Pa, Ga	Nil	Nil
Ramdasi Malhar	Ma	Sa, KNi, Ni	Re, Dha	Pa, Ga, KGa	Nil	Nil
Sampurna Malkauns	Ma	Sa, KNi	Re, KDha	Pa, KGa	Nil	Nil
Saurashtra Tank	Ma	Sa, Ni	KRe, Dha, KDha	Pa, Ga	Nil	Nil
Shukla Bilawal	Ma	Sa, Ni, KNi	Re, Dha	Pa, Ga	Nil (Re)	Nil
Sindh Bhairavi	Ma	Sa, KNi	Re, KDha	Pa, KGa	Nil	Nil
Tribhuvan Malhar	Ma	Sa, KNi, Ni	Re, Dha	Pa, KGa, Ga	Nil	Nil
*Utari Gunakali*1	Ma	Sa, KNi	KRe, KDha	Pa, KGa	Nil	Nil
*Utari Gunakali*2	Ma	Sa, KNi, Ni	Re, Dha	Pa, Ga	Nil	Nil

Madhyama Gana: Shadava-Shadava Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Ahir Lalit	Ma, Mat	Sa, KNi	KRe, Dha	Ga	Pa	Pa
Bahar	Ma	Sa, Ni, KNi	Re	Pa, KGa	Re	Dha
Chakradhar	Ma	Sa, Ni	Re, Dha	Ga	Pa	Pa
Chandani Kedar	Ma, Mat	Sa, Ni	Re, Dha	Pa	Ga	Ga
Gorakh Kalyan	Ma	Sa, KNi	Re, Dha	Pa	Ga	Ga
Jog Kauns	Ma	Sa, Ni, KNi	KDha	Pa, Ga, KGa	Re	Re
Kaishiki Ranjani	Ma	Sa, Ni	Re, KDha	KGa	Pa	Pa
Kedar Malhar (Savani Kedar)	Ma, Mat	Sa, Ni, KNi	Re, Dha	Pa	Ga	Ga
Lalit	Ma, Mat	Sa, Ni	KRe, Dha	Ga	Pa	Pa
Malav	Ma	Sa, KNi	Dha, KDha	Pa, Ga, KGa	Re	Re
Nat Kuranjika	Ma	Sa, KNi	Re, Dha	Ga	Pa	Pa
Nayaki Kanada	Ma	Sa, KNi	Re	Pa, KGa	Dha	Dha
*Nayaki Kanada*1	Ma	Sa, KNi	Re	Pa, KGa	Dha	Dha
Nayaki Kanada 2	Ma	Sa, (Ni), KNi	Re	Pa, KGa	Dha	Dha

Table to be continued

Pancham	Ma, Mat	Sa, Ni	KRe, Dha	Ga	Pa	Pa
Shri Ranjani	Ma	Sa, KNi	Re, Dha	KGa	Pa	Pa
Shyam Kedar	Ma, Mat	Sa, Ni, KNi	Re, Dha	Pa	Ga	Ga
Sudha Ranjani	Ma	Sa, Ni (Teevra Madhyam Bhav)	Re, Dha	KGa	Pa	Pa
Suha	Ma	Sa, KNi	Re	Pa, KGa	Dha (Re), (Ni)	Dha
Suha Type 2	Ma	Sa, KNi, Ni	Re	Pa, KGa	KDha (Re)	(KDha)

Madhyama Gana: Oudava-Oudava Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Aabhogi	Ma	Sa	Re, Dha	KGa	Pa, Ni	Pa, Ni
Aabhogi Kanada	Ma	Sa	Re, Dha	KGa	Pa, Ni	Pa, Ni
Bairagi	Ma	Sa, KNi	KRe	Pa	Ga, Dha	Ga, Dha
Bhinna Shadja	Ma	Sa, Ni	Dha	Ga	Re, Pa	Re, Pa
Chandra Kauns (Bageshri Type)	Ma	Sa, KNi	Dha	KGa	Re, Pa	Re, Pa
Chandra Kauns (Malkauns Type)	Ma	Sa, Ni	KDha	KGa	Re, Pa	Re, Pa
Dev Ranjani	Ma	Sa, KNi	KDha	Pa	Re, Ga	Re, Ga
Dugam Hindol	Ma, Mat	Sa	Dha	Ga, KGa	Pa, Ni	Pa, Ni
Durga (Bilaval)	Ma	Sa	Re, Dha	Pa	Ga, Ni	Ga, Ni
Jaladhar Kedar	Ma	Sa	Re, Dha	Pa	Ga, Ni	Ga, Ni
Madhu Suraja	Ma, Mat	Sa, KNi	Re, KRe	Pa	Ga, Dha	Ga, Dha
Malkauns	Ma	Sa, KNi	KDha	KGa	Re, Pa	Re, Pa
Megha Ranjani	Ma	Sa	KRe	Ga	Pa, Dha	Pa, Dha
Nag Swravali	Ma	Sa	Dha	Pa, Ga	Re, Ni	Re, Ni
Naga Swarali	Ma	Sa, Ni	Re, Dha	Pa, Ga	Re, Ni (Pa)	Re, Ni
Rajeshwari	Ma	Sa, Ni	Dha	KGa	Re, Pa	Re, Pa
Rasa Chandra	Ma, Mat	Sa	Re, Dha	Ga	Ni, Pa	Ni, Pa
Shobhavari	Ma	Sa	KDha, Re	Pa	Ga, Ni	Ga, Ni

Table to be continued

Shuddha Malhar (Type 1)	Ma	Sa	Re, Dha	Pa	Ga, Ni	Ga, Ni
Sudha Jogiya	Ma	Sa	Dha, KRe	Pa	Ga, Ni	Ga, Ni

Madhyama Gana: Shadava-Sampurna Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Anjani Todi	Ma	Sa, Ni, KNi	Re, Dha, KDha	Pa, KGa	KGa	Nil
Bageshri	Ma	Sa, KNi	Re, Dha	Pa, KGa	Pa	Nil
Basant	Ma, Mat	Sa, Ni	KRe, KDha	Pa, Ga	Pa	Nil
Bhairav Bahar	Ma	Sa, Ni, KNi	KRe, Dha	Pa, Ga	Pa	Nil
Bihagada	Ma	Sa, Ni, (KNi)	Re, Dha	Pa, Ga	Re, (Dha)	Nil
Dhuliya Malhar	Ma	Sa, Ni, KNi	Re, Dha	Pa, KGa	Dha	Nil
Lalit Bhairav	Ma	Sa, Ni	KRe, KDha	Pa, Ga	Pa	Nil
Lalit Pancham	Ma, Mat	Sa, Ni	KRe, KDha	Pa, Ga	Pa	Nil
Malgunji	Ma	Sa, Ni, KNi	Re, Dha	Pa, Ga, KGa	Pa	Nil
Nat Bilawal	Ma	Sa, Ni, KNi	Dha	Pa, Ga	Re	Nil
Pat Bihag	Ma	Sa, Ni, (KNi)	Re, Dha	Pa, Ga	Dha	Nil
Pitambar Bhairav	Ma, Mat	Sa, Ni	KRe, KDha	Pa, Ga	Pa	Nil

Madhyama Gana: Sampurna-Shadava Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Miya Malhar	Ma	Sa, Ni, KNi	Re, Dha	Pa, KGa	Nil	Dha
Shiva Kauns	Ma	Sa, Ni	Re, KDha	Pa, KGa	Nil (Pa)	Re

Madhyama Gana: Oudava-Sampurna Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Aabheri	Ma	Sa, KNi	KRe, KDha	Pa, KGa	KRe, KDha	Nil
Aanandi Kedar	Ma, Mat	Sa, Ni	Re, Dha	Pa, Ga	Re, Ga	Nil
Aasa	Ma	Sa, Ni	Re, Dha	Pa, Ga	Ga, Ni	Nil
Bageshri	Ma	Sa, KNi	Re, Dha	Pa, KGa	Re, Pa	Nil
Bhimpalasi	Ma	Sa, KNi	Re, Dha	Pa, KGa	Re, Dha	Nil
Bhinna Bhairav	Ma	Sa, Ni	KRe, Dha	Pa, Ga	KRe, Pa	Nil, (Pa)
Champak	Ma	Sa, KNi	Re, Dha	Pa, Ga	Ga, KNi	Nil
Gagan Vihang	Ma	Sa, Ni	Re, Dha	Pa, Ga	Re, Dha	Nil
Hamsa Kinkini (Bageshri Type)	Ma	Sa, Ni, KNi	Re, Dha	Pa, Ga, KGa	Re, Pa	Nil
Hemant	Ma	Sa, Ni	Re, Dha	Pa, Ga	Re, Pa	Nil
Kaunsi Bhairav-1	Ma	Sa, KNi	KRe, KDha	Pa, Ga	(KRe), Pa	Nil, (Pa)
Kedar	Ma, Mat	Sa, Ni, (KNi)	Re, Dha	Pa, Ga	Re, Ga	Nil (Ga)
Madhava	Ma	Sa, KNi	Re, Dha	Pa, Ga	Re, Pa	Nil
Maluha Kedar	Ma	Sa, Ni	Re, Dha	Pa, Ga	Re, Dha	Nil
Pradipaki	Ma	Sa, KNi	Re, Dha	Pa, Ga, KGa	Re, Dha	Nil
Rageshri Bahar	Ma	Sa, Ni, KNi	Re, Dha	Pa, Ga, KGa	Re, Pa	Nil
Sajan	Ma	Sa, Ni, KNi	Re, Dha	Pa, Ga	Re, Pa	Nil
Shyam Kalyan	Ma, Mat	Sa, Ni	Re, Dha	Pa, Ga	Ga, Dha	Nil

Table to be continued

Vasant Pancham	Ma, Mat	Sa, Ni	KRe, KDha	Pa, Ga	Re, Pa	Nil

Madhyama Gana: Sampurna-Oudava Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Nat	Ma	Sa, Ni	Re, Dha	Pa, Ga	Nil	Dha, Ga, (KNi)

Madhyama Gana: Oudava-Shadava Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Durga Bhairav	Ma	Sa	KRe, Dha	Pa, Ga	Ga, Ni	Ni
Jogiya	Ma	Sa, Ni	KRe, KDha	Pa	Ga, Ni	Ga
Kamal Mano-hari	Ma	Sa, Ni	Re, KDha	Ga	Re, KDha	Re
Pancham Malkauns	Ma	Sa, KNi	Re, KDha	KGa	Re, Pa	Pa
Shri Ranjani	Ma	Sa, KNi	Re, Dha	KGa	Re, Pa	Pa
Sur Malhar	Ma	Sa, Ni, KNi	Re, Dha	Pa	Ga, Dha	Ga
Tilang Bhairav	Ma	Sa, Ni, KNi	KRe	Ga	KRe, Dha	Dha
Vinay Bhairav	Ma	Sa, KNi	KRe, Dha	Ga	KRe, Pa	Pa

Madhyama Gana: Shadava-Oudava Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Jayaraj	Ma	Sa, Ni	Re, Dha	Pa	Ga	Ga, Ni

Gandhara Gana Ragas

Gandhara Gana: Sampurna-Sampurna Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Gaud Sarang	Ga	Ni, Dha	Pa, Sa	Ma, Mat, Re	Nil	Nil
Jhinjoti	Ga	Dha, KNi	Pa, Sa	Ma, Re	Nil	Nil
Khamaji Malhar	Ga	Dha, Ni, KNi	Pa, Sa	Ma, Re	Nil	Nil
Khamaji Sarang	Ga	Dha, Ni, KNi	Pa, Sa	Ma, Re	Nil	Nil
Poorvi	Ga	Ni, KDha	Pa, Sa	Ma, Mat, KRe	Nil	Nil
Puriya Kalyan	Ga	Ni, Dha	Pa, Sa	Mat, KRe	Nil (Pa)	Nil
Puriya Vasant	Ga	Ni, Dha, KDha	Pa, Sa	Mat, KRe	Nil	Nil
Sajagiri	Ga	Ni, Dha, KDha	Pa, Sa	Ma, Mat, KRe	Nil	Nil
Varati (Barati/ Barari)	Ga	Ni, Dha	Pa, Sa	Mat, KRe	Nil	Nil
Yaman	Ga	Ni, Dha	Pa, Sa	Mat, Re	Nil	Nil

Gandhara Gana: Shadava-Shadava Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Hamsa Narayani	Ga	Ni, Dha	Sa	Mat, KRe	Dha	Dha
Puriya	Ga	Ni, Dha	Sa	Mat, KRe	Pa	Pa
Purvya	Ga	Ni, Dha, KDha	Sa	Mat, KRe	Pa	Pa
Raj Kalyan	Ga	Ni, Dha	Sa	Mat, Re	Pa, (Re)	Pa

Gandhara Gana: Oudava-Oudava Ragas

Name	Vadi	Samvadi	Anuvadi	Anu-Anuvadi	Arohi Varjya	Avrohi Varjya
Bhupali or Bhoop	Ga	Dha	Pa, Sa	Re	Ma, Ni	Ma, Ni
Durga (Khamaj Type)	Ga	Dha, Ni, KNi	Sa	Mat	Re, Pa	Re, Pa
Hamsadhwani	Ga	Ni	Pa, Sa	Re	Ma, Dha	Ma, Dha
Hindol (Sanz or Sanz ka Hindol)	Ga	Ni, Dha	Sa	Mat	Pa, Re	Pa, Re
Tilang	Ga	Ni, KNi	Pa, Sa	Ma	Re, Dha	Re, Dha

Gandhara Gana: Shadava-Sampurna Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Chandrakant	Ga	Ni, Dha	Pa, Sa	Mat, Re	Mat	Nil
Dipak-1 (Bilawal Type)	Ga	Dha, Ni, KNi	Pa, Sa	Ma, Re	Re	Nil
Khamaj	Ga	Dha, KNi	Pa, Sa	Ma, Re	Re	Nil
Manohar	Ga	Ni, KDha	Pa, Sa	Mat, KRe	Pa	Nil
Nat Bihag	Ga	Dha, Ni, (KNi)	Pa, Sa	Ma, Re	Dha	Nil

Gandhara Gana: Sampurna-Shadava Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Khambavati	Ga	Dha, Ni, KNi	Pa, Sa	Ma, Re	Nil	Re

Gandhara Gana: Oudava-Sampurna Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Bihag	Ga	Ni, Dha	Pa, Sa	Ma, (Mat), Re	Re, Dha	Nil
Jaitashri	Ga	Ni, KDha	Pa, Sa	Mat, KRe	KRe, KDha	Nil
Maru Bihag	Ga	Ni, Dha	Pa, Sa	Ma, Mat, Re	Re, Dha	Nil
Shuddha Kalyan	Ga	Ni, Dha	Pa, Sa	Mat, Re	Mat, Ni	Nil
Tribhuvan Mohini	Ga	Dha, KNi	Pa, Sa	Ma, Re	Re, Dha	Nil

Gandhara Gana: Sampurna-Oudava Ragas

There are no existing *Ragas* for this category.

Gandhara Gana: Oudava-Shadava Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Dhanakoni	Ga	KNi (Teevra Madhyam Bhav)	Sa	Mat, Re	Dha, Re	Dha
Malin	Ga	Ni, Dha	Pa, Sa	KRe	Ma, KRe	Ma
Rageshri	Ga	Ni, KNi, Dha	Sa	Ma, Re	Pa, Re	Pa
Ragesh-wari	Ga	Ni, KNi, Dha	Sa	Mat, Re	Pa, Re	Pa
Raj Kalyan	Ga	Ni, Dha	Sa	Mat, Re	Pa, Re	Pa
Shankara	Ga	Ni, Dha	Pa, Sa	Re	Ma, Re	Ma

Gandhara Gana: Shadava-Oudava Ragas

There are no existing *Ragas* for this category.

Komal Gandhara Gana Ragas

Komal Gandhara Gana: Sampurna-Sampurna Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Pilu	KGa	KNi, KDha	Pa, Sa	Ma, Re	Nil	Nil

Komal Gandhara Gana: Shadava-Shadava Ragas

There are no existing *Ragas* for this category.

Komal Gandhara Gana: Oudava-Oudava Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anu-vadi***	***Arohi Varjya***	***Avrohi Varjya***
Dhani (Dhani Kauns)	KGa	KNi	Pa, Sa	Ma	Re, Dha	Re, Dha
Oudava Todi (Chhaya Todi or Firojkhani Todi)	KGa	KDha	Sa	KRe, Mat	Pa, Ni	Pa, Ni

Komal Gandhara Gana: Shadava-Sampurna Ragas

There are no existing *Ragas* for this category.

Komal Gandhara Gana: Sampurna-Shadava Ragas

There are no existing *Ragas* for this category.

Komal Gandhara Gana: Oudava-Sampurna Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Dev Gandhar (Dhani Type)	KGa	KNi, KDha	Pa, Sa	Ma, Re	Re, KDha	Ni

Komal Gandhara Gana: Sampurna-Oudava Ragas

There are no existing *Ragas* for this category.

Komal Gandhara Gana: Oudava-Shadava Raga

There are no existing *Ragas* for this category.

Komal Gandhara Gana: Shadava-Oudava Ragas

There are no existing *Ragas* for this category.

Rishabha Gana Ragas

Rishabha Gana: Sampurna-Sampurna Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anu-vadi***	***Arohi Varjya***	***Avrohi Varjya***
Chandramukhi Kanada	Re	Pa, Dha	Ma, KNi, Ni	Sa, KGa	Nil	Nil
Chhaya Malhar	Re	Pa, Dha	Ma, Ni, KNi	Sa, Ga	Nil	Nil
Desha	Re	Pa, Dha	Ma, Ni, KNi	Sa, Ga	Nil	Nil
Desha Malhar (Jayant Malhar)	Re	Pa, Dha	Ma, Ni, KNi	Sa, Ga, KGa	Nil	Nil
Huseni Kanada	Re	Pa, Dha	Ma, KNi	Sa, KGa	Nil	Nil
Huseni Kanada Type 2	Re	Pa, Dha, KDha	Ma, KNi	Sa, KGa	Nil	Nil
Jayant Kanada Type 1	Re	Pa, Dha	Ma, KNi, Ni	Sa, KGa, Ga	Nil	Nil
Jayant Sarang	Re	Pa, Dha	Ma, Ni, KNi	Sa, Ga, KGa	(Ga), (Dha),Nil	Nil
Jayjayvanti	Re	Pa, Dha	Ma, Ni, KNi	Sa, Ga, KGa	Nil	Nil
Khokar	Re	Pa, Dha	Ma, KNi	Sa, Ga, KGa	Nil	Nil
Kiravani	Re	Pa, KDha	Ma, Ni	Sa, KGa	Nil	Nil
Lakshmi Kalyan	Re	Pa, Dha	Ma, Mat, Ni	Sa, Ga	Nil	Nil

Table to be continued

Lakshmi Kalyan	Re	Pa, Dha	Ma, Mat, Ni	Sa, Ga	Nil	Nil
Nindiyari	Re	Pa, Dha	Ma, Mat, Ni	Sa, Ga	Nil	Nil
Sindh	Re	Pa, Dha	Ma, Ni, KNi	Sa, Ga, KGa	Nil	Nil
Vinay Sarang	Re	Pa, Dha	Ma, Ni, KNi	Sa, Ga	Nil	Nil

Rishabha Gana: Shadava-Shadava Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Ambika Sarang	Re	Pa, Dha	Ma, Mat, Ni, KNi	Sa	Ga	Ga
Hamsa Kalyani	Re	Pa, Dha	Ni	Sa, Ga	Ma	Ma
Jaimini Sarang	Re	Pa, Dha	Mat, Ni, KNi	Sa	Ga	Ga
Miya ki Sarang	Re	Pa, Dha	Ma, Ni, KNi	Sa	Ga	Ga
Shuddha Sarang	Re	Pa, Dha	Ma, Mat, Ni, KNi	Sa	Ga	Ga (Dha)

Rishabha Gana: Oudava-Oudava Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Badahans Sarang	Re	Pa	Ma, Ni, KNi	Sa	Ga, Dha	Ga, Dha
Brindavani Sarang	Re	Pa	Ma, Ni, KNi	Sa	Ga, Dha	Ga, Dha
Madha-Mada Sarang	Re	Pa	Ma, KNi	Sa	Ga, Dha	Ga, Dha
Maluha Sarang	Re	Pa, Dha	Ma, Ni	Sa	Ga, Dha	Ga, Ni
Salang Sarang	Re	Pa, Dha	Ma, Ni	Sa	Ga, Dha	Ga, Dha
Samant Sarang	Re	Pa	Ma, Ni, KNi	Sa	Ga, Dha	Ga, Dha
Shiv Abhogi	Re	Dha	Mat	Sa, KGa	Pa, Ni	Pa, Ni

Rishabha Gana: Shadava-Sampurna Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Barva	Re	Pa, Dha	Ma, Ni, KNi	Sa, KGa	KGa	Nil
Dhuliya Sarang (Type 1)	Re	Pa, Dha	Ma, KNi, Ni	Sa, Ga	Dha	Nil
Jaij Bilawal	Re	Pa, Dha	Ma, KNi, Ni	Sa, Ga	Dha	Nil
Shyam Sarang	Re	Pa, Dha	Ma, Mat, Ni	Sa, Ga	Dha	Nil
Sorat Malhar	Re	Pa, Dha	Ma, Ni, KNi	Sa, Ga	Ga	Nil
Tilak Kamod	Re	Pa, Dha	Ma, Ni	Sa, Ga	Dha	Nil

Rishabha Gana: Sampurna-Shadava Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Darbari Kanada	Re	Pa, KDha	Ma, KNi	Sa, KGa	Nil	KDha

Rishabha Gana: Oudava-Sampurna Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Neelambari	Re	Pa, Dha	Ma, Ni, KNi	Sa, Ga, KGa	Ga, KGa, Ni, KNi	Nil
Malavati	Re	Pa, Dha	Ma, Ni	Sa, Ga	Ga, Ni	Nil
Sorath	Re	Pa, Dha	Ma, Ni, KNi	Sa	Ga, Dha	Nil, (Ga)
Sorati Kanada	Re	Pa, Dha	Ma, KNi, Ni	Sa, KGa	KGa, Dha	Nil
Lanka Dahan Sarang	Re	Pa, Dha	Ma, KNi, Ni	Sa, KGa	KGa, Dha	Nil

Rishabha Gana: Sampurna-Oudava Ragas

There are no existing *Ragas* for this category.

Rishabha Gana: Oudava-Shadava Ragas

Name	Vadi	Samvadi	Anuvadi	Anu-Anuvadi	Arohi Varjya	Avrohi Varjya
Dhuliya Sarang (Type 2)	Re	Pa	Ma, KNi	Sa, Ga	Ga, Dha	Ga
Narayani	Re	Pa, Dha	Ma, KNi	Sa, Ga	Ga, KNi	Ga
Noor Sarang	Re	Pa	Mat, Ni	Sa, Ga	Ga, Dha	Ga
Shuddha Sarang	Re	Pa	Ma, Mat, KNi, Ni	Sa, Ga	Ga, Dha	Ga
Tilak Sarang (Meera Sarang)	Re	Pa	Ma, KNi, Ni	Sa, Ga	Ga, Dha	Dha

Rishabha Gana: Shadava-Oudava Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Nat Sarang	Re	Pa, Dha	Ma, KNi, Ni	Sa, Ga	Dha	Ga, Dha

Komal Rishabha Gana Ragas

Komal Rishabha Gana: Sampurna-Sampurna Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Bhairav Bhatiyar	KRe	Pa, KDha, Dha	Ma, Ni	Sa, Ga	Nil	Nil
Gauri (Bhairav)	KRe	Pa, KDha, Dha	Mat, Ni	Sa, Ga	Nil	Nil
Mali Gaura	KRe	KDha, Dha, Pa	Mat, Ni	Sa, Ga	Nil	Nil

Komal Rishabha Gana: Shadava-Shadava Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Malavi	KRe	Pa, KDha	Ni, Mat	Sa, Ga	Ni	KDha
Triveni	KRe	Pa, KDha	Ni	Sa, Ga	Ma	Ma

Komal Rishabha Gana: Oudava-Oudava Ragas

There are no existing *Ragas* for this category.

Komal Rishabha Gana: Shadava-Sampurna Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Malavi	KRe	Pa, KDha	Mat, Ni	Sa, Ga	Ni	Nil

Komal Rishabha Gana: Sampurna-Shadava Ragas

There are no existing *Ragas* for this category.

Komal Rishabha Gana: Oudava-Sampurna Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Gauri (Bhairav)	KRe	Pa, KDha	Ma, Ni	Sa, Ga	Ga, KDha	Nil
Gauri (Poorvi)	KRe	Pa, KDha	Ma, Mat, Ni	Sa, Ga	Ga, KDha	Nil
Shree	KRe	Pa, KDha	Mat, Ni	Sa, Ga	Ga, KDha	Nil

Komal Rishabha Gana: Sampurna-Oudava Ragas

There are no existing *Ragas* for this category.

Komal Rishabha Gana: Oudava-Shadava Ragas

There are no existing *Ragas* for this category.

Komal Rishabha Gana: Shadava-Oudava Ragas

There are no existing *Ragas* for this category.

Dhaivat Gana Ragas

Dhaivat Gana: Sampurna-Sampurna Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Alaihya Sarang	Dha	Ga, Re	Sa, Ma	Pa, Ni, KNi	Nil	Nil
Bilawal	Dha	Ga, Re	Sa, Ma	Pa, Ni	Nil	Nil
Gaud Bilawal (Bilawal Malhar)	Dha	Ga, Re	Sa, Ma	Pa, Ni, KNi	Nil	Nil
Hameer	Dha	Ga, Re	Sa, Ma, Mat	Pa, Ni	Nil	Nil
Lachchhsakh	Dha	Ga, Re	Sa, Ma	Pa, Ni, KNi	Nil	Nil
Vibhas (Marava)	Dha	Ga, KRe	Sa, Mat	Pa, Ni	Nil	Nil

Dhaivat Gana: Shadava-Shadava Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Lalitavari	Dha	Ga, KRe	Sa, Ma, Mat	Ni	Pa	Pa
Malati Vasant	Dha	Ga, KRe	Sa, Ma, Mat	Ni	Pa	Pa
Marava	Dha	Ga, KRe	Sa, Mat	Ni	Pa	Pa
Sohani	Dha	Ga, KRe	Sa, Mat	Ni	Pa (KRe)	Pa

Dhaivat Gana: Oudava-Oudava Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Deshkar	Dha	Ga, Re	Sa	Pa	Ma, Ni	Ma, Ni
Gorakh Kalyan	Dha	Re	Sa, Ma	KNi	Ga, Pa	Ga, Pa
Hindol	Dha	Ga	Sa, Ma	Ni	Re, Pa	Re, Pa
Rasa Ranjani	Dha	Re	Sa, Ma	Ni	Ga, Pa	Ga, Pa

Dhaivat Gana: Shadava-Sampurna Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Alaihya Bilaval	Dha	Ga, Re	Sa, Ma	Pa, Ni, KNi	Ma	Nil

Dhaivat Gana: Sampurna-Shadava Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Sampurna Hindol	Dha	Ga	Sa, Mat	Ni	Re, Pa	Re, Pa

Dhaivat Gana: Oudava-Sampurna Ragas

There are no existing *Ragas* for this category.

Dhaivat Gana: Sampurna-Oudava Ragas

There are no existing *Ragas* for this category.

Dhaivat Gana: Oudava-Shadava Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Kamal Ranjani	Dha	Ga	Sa, Ma	Pa, Ni, KNi	Re, Ma	Re

Dhaivat Gana: Shadava-Oudava Ragas

There are no existing *Ragas* for this category.

Komal Dhaivat Gana Ragas

Komal Dhaivat Gana: Sampurna-Sampurna Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Bahaduri Todi	KDha	KGa, KRe, (Re)	Sa, Mat	(Pa), Ni	Nil	Nil
Bhairav	KDha	Ga, KRe	Sa, Ma	Pa, Ni	Nil	Nil
Bilaskhani Todi	KDha	KGa, KRe	Sa, Ma	Pa, KNi	Nil (Ma, KNi)	Nil
Kabeer Bhairav-2	KDha	Ga, KRe	Sa, Ma	Pa, Ni, KNi	Nil	Nil
Khat	KDha	KGa, Re	Sa, Ma	Pa, KNi, Ni	Nil	Nil
Komal Bhairav	KDha	Ga, KGa, KRe	Sa, Ma	Pa, Ni, KNi	Nil	Nil
Shivamat Bhairav	KDha	Ga, KGa, KRe	Sa, Ma	Pa, Ni, KNi	Nil	Nil
Sindh Bhairavi	KDha (Dha)	KGa, Re, (KRe)	Sa, Ma	Pa, KNi	Nil	Nil
Todi	KDha	KGa, KRe	Sa, Mat	(Pa), Ni	Nil	Nil
Utari Gunakali (Bhairavi Type)	KDha	KGa, KRe,	Sa, Ma	Pa, KNi	Nil	Nil
Varati Todi	KDha	KGa, KRe	Sa, Mat	Pa, KNi	Nil	Nil
Zilaph	KDha	KGa, Re, (Ga)	Sa, Ma	Pa, KNi	Nil	Nil

Komal Dhaivat Gana: Shadava-Shadava Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Bangal Bhairav	KDha	Ga, KRe	Sa, Ma	Pa	Ni	Ni
Gujari Todi	KDha	KGa, KRe	Sa, Mat	Ni	Pa	Pa
Mangal Bhairav-2	KDha	KRe, Ni	Sa, Ma	Pa	Ga	Ga

Komal Dhaivat Gana: Oudava-Oudava Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Bhupal Todi	KDha	KGa, KRe	Sa	Pa	Ma, Ni	Ma, Ni
Gunakari (Bhairav Type)	KDha	Ga, KRe	Sa, Ma	Pa	Ga, Ni	Ga, Ni
Vibhas (Bhairav Type)	KDha	Ga, KRe	Sa	Pa	Ma, Ni	Ma, Ni

Komal Dhaivat Gana: Shadava-Sampurna Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Asavari Todi	KDha	KGa, Re, KRe	Sa, Ma, Mat	Pa, KNi	KNi	Nil
Dev Gandhar	KDha	KGa, Ga, Re	Sa, Ma	Pa, KNi	KGa, Ga	Nil
Gandhari	KDha	KGa, KRe, Re	Sa, Ma	Pa, Ni, KNi	KGa	Nil
Jaunpuri	KDha	KGa, Re	Sa, Ma	Pa, KNi	KGa	Nil

Komal Dhaivat Gana: Sampurna-Shadava Ragas

There are no existing *Ragas* for this category.

Komal Dhaivat Gana: Oudava-Sampurna Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Asavari	KDha	KGa, Re	Sa, Ma	Pa, KNi	KGa, KNi	Nil

Komal Dhaivat Gana: Sampurna-Oudava Ragas

There are no existing *Ragas* for this category.

Komal Dhaivat Gana: Oudava-Shadava Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Saheli Todi	KDha	KGa, KRe	Sa	Pa, KNi	Ma, KNi	Ma
Vibhas (Poorvi Type)	KDha	Ga, KRe	Sa, (Mat)	Pa	Ma, (Ni)	Ma

Komal Dhaivat Gana: Shadava-Oudava Ragas

There are no existing *Ragas* for this category.

Prakirna Gana Ragas

Prakirna Gana: Sampurna-Sampurna Ragas

Name	*Vadi*	*Samvadi*	*Anuvadi*	*Anu-Anuvadi*	*Arohi Varjya*	*Avrohi Varjya*
Asavari Bhairav (Prakirna)	Pa	Sa, Re, KRe	Ga, KGa, Ni, KNi	Ma, KDha	Nil	Nil
Basanti Kedar (Prakirna)	Ma, Mat	Sa, Ni, KNi	Re, KRe, Dha, KDha	Pa, Ga	Re	Nil
Basanti Malhar (Ma Vadi)	Ma, Mat	Sa, Ni, KNi	Re, KRe, Dha, KDha	Pa, Ga	Nil	Nil
Basanti Malhar (Sa Vadi)	Sa	Pa, Ma, Mat	Ga, Dha, KDha	Re, KRe, Ni, KNi	Nil	Nil
Gunji Kanada	Ma	Sa, Ni, KNi	Re, Dha, KDha	Pa, KGa, Ga	Nil	Nil
Jayant Kanada Type 2	Re	Pa, Dha, KDha	Ma, KNi, Ni	Sa, KGa, Ga	Nil	Nil
Jounpuri Bhairav	Pa	Sa, Re, KRe	Ga, KGa, Ni, KNi	Ma, KDha	Nil	Nil
Jounpuri Bhairav	Pa	Sa, Re, KRe	Ga, KGa, Ni, KNi	Ma, KDha	Nil	Nil
Kausi Bhairav	Ma	Sa, KNi, Ni	KRe, Re, KDha, Dha	Pa, Ga	Nil	Nil
Khat (Pa Vadi)	Pa	Sa, Re, KRe	Ga, KGa, Ni, KNi	Ma, Dha, KDha	Nil	Nil
Khat (Sa Vadi)	Sa	Pa, Ma	Ga, KGa, Dha, KDha	Re, KRe, Ni, KNi	Nil	Nil

Table to be continued

Khat Todi (KDha Vadi)	KDha	KGa, Re, Kre	Sa, Ma, Mat	Pa, Ni, KNi		
Khat Todi	Sa	Pa, Ma, Mat	Kga, Kdha	Re, Kre, Ni, KNi	Nil	Nil
Lakshmi Todi (Ma Vadi)	Ma	Sa, KNi	Re, Kre, Dha, Kdha	Pa, Ga, Kga	Nil	Nil
Lakshmi Todi (Sa Vadi)	Sa	Pa, Ma	Ga, KGa, Dha, Kdha	Re, Kre, KNi	Nil	Nil
Meera Malhar	Pa	Sa, Re	Ga, KGa, Ni, KNi	Ma, Dha, KDha	Nil	Nil
Meera Malhar (Sa Vadi)	Sa	Pa, Ma	Ga, KGa, Dha, KDha	Re, Ni, KNi	Nil	Nil
Motaki	Sa	Pa, Ma, Mat	KGa, Dha, KDha	Re, KRe, Ni, KNi	Nil	Nil
Motaki (Pa Vadi)	Pa	Sa, Re, KRe	KGa, Ni, KNi	Ma, Mat, Dha, KDha	Nil	Nil
Pilu (Pa Vadi)	Pa	Sa, Re	Ga, KGa, Ni, KNi	Ma, Dha, KDha		
Pilu (Sa Vadi)	Sa	Pa, Ma	Ga, KGa, Dha, KDha	Re, Ni, KNi	Nil	Nil
Sohan Malhar (Dha Vadi)	Dha	Ga, Re, KRe	Sa, Ma, Mat	Pa, Ni, KNi	Nil	Nil
Sohan Malhar (Sa Vadi)	Sa	Pa, Ma, Mat	Ga, Dha	Re, KRe, Ni, KNi	Nil	Nil
Vasant Bahar (Ma Vadi)	Ma, Mat	Sa, Ni, KNi	Re, KRe, Dha, KDha	Pa, Ga, KGa	Nil	Nil
Vasant Bahar (Sa Vadi)	Sa	Pa, Ma, Mat	Ga, KGa, Dha, KDha	Re, KRe, Ni, KNi	Nil	Nil

Prakirna Gana: Shadava-Shadava Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Lagan Gandhar (Tri-Gandhar Category)	Sa	Pa	Ga, KGa, BGa, Dha	Re, Ni, KNi, BNi	Ma	Ma

Prakirna Gana: Oudava-Oudava Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Kshanika	Sa	Ma	KDha	KRe, Ni	Ga, Pa	Ga, Pa

Table to be continued

Malarani (Pa Vadi) (Different Vrj Swaras)	Pa	Sa, Re	Ga, Ni	Dha, Mat	Ga, Dha	Ni, Mat
Malarani (Different Vrj Swaras)	Sa	Pa, Mat	Ga, Dha	Re, Ni	Ga, Dha	Ni, Mat

Prakirna Gana: Shadava-Sampurna Ragas

There are no existing *Ragas* for this category.

Prakirna Gana: Sampurna-Shadava Ragas

There are no existing *Ragas* for this category.

Prakirna Gana: Oudava-Sampurna Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Jogi Asavari	Sa	Pa, Ma	Ga, KGa, KDha	Re, KRe, Ni, KNi	Ga, KGa, Ni, KNi	Nil
Sanjari	Sa	Pa, Ma, Mat	Ga, KGa, Dha	Re, Ni, KNi	Ga, KGa, Ni, KNi	Nil

Prakirna Gana: Sampurna-Oudava Ragas

There are no existing *Ragas* for this category.

Prakirna Gana: Oudava-Shadava Ragas

Name	***Vadi***	***Samvadi***	***Anuvadi***	***Anu-Anuvadi***	***Arohi Varjya***	***Avrohi Varjya***
Bhavamat Bhairav (Ma Vadi)	Ma, Mat	Sa, KNi	KRe, Dha	Pa, Ga	Re, Pa	KNi
Bhavamat Bhairav (Sa Vadi)	Sa	Pa, Ma, Mat	Ga, Dha	KRe, KNi	Re, Pa	KNi
Gavati (Ga Vadi)	Ga	Dha, KNi	Sa, Pa	Ma, Re	Re, Dha	KNi
Gavati (Pa Vadi)	Pa	Sa, Re	Ga, KNi	Ma, Dha	Re, Dha	KNi
Gavati (Prakirna)	Sa	Pa, Ma	Ga, Dha	Re, KNi	Re, Dha	KNi
Komal Rishabh Asavari	KDha	KGa, KRe	Sa, Ma	Pa, KNi	KGa, KNi	Pa

Prakirna Gana: Shadava-Oudava Ragas

There are no existing *Ragas* for this category.

Prakirna Gana: Chatuh Swari Ragas

There are no existing *Ragas* for this category.

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APPENDIX V

Nava Gana Classification of Contemporary *Talas*

Introduction

The *Nava Gana* system is developed because it is difficult to properly classify the contemporary *Talas* as per the traditional norms. The major issue arises due to three or four different traditions of *Talas* that are prevalent currently in India such as the North Indian *Talas*, *Suladi Sapta Talas*, and the *Chapu Talas* of Carnatic music and the ancient *Talas* described in treatises. The *Nava Gana* system accommodates all the existing *Talas* including ancient, medieval and the contemporary *Talas*. It synthesizes the traditional *Anga* system prevalent in Carnatic music with the *Vibhaga* system of North Indian music seamlessly. The new vocabulary of *Tala Bols* taking *Tabla Bols* as the basic units to represent percussion strokes brings in a kind of uniformity across diverse *Tala* systems prevalent today. This does justice to the temporal aesthetics of *Tala* as well as the psycho-acoustic aesthetics of *Tala*.

The following description uses a particular way of representing and describing all the *Talas* including North Indian and Carnatic *Talas.* It uses a sophisticated system developed in Carnatic music for showing the *Anga* structure of a *Tala*. For showing the *Anga* structure symbols like ‘I’, ‘O’, and ‘U’ are used. To show *Suladi Sapta Talas* this system is used traditionally. Accordingly, ‘I’ represents the *Anga* value in terms of the number of *Matras* or *Aksharas* and it is variable as per the *Jati/ Gana* of the *Tala*. For instance, the *Chatarashra Gana* value of ‘I’ will be 4 because the number of *Matras* in the *Anga* of a *Chatarashra Gana* is 4, while for *Tryashra Jati/ Gana* the value of ‘I’ will be 3 for the same reason. Values of ‘O’ and ‘U’ are fixed. ‘O’ and ‘U’ normally represent the parts of the *Upanga*. ‘O’ is called *Druta* and it has a fixed value of 2 *Matras* or *Aksharas*. ‘U’ is called *Anudruta* and it has a fixed value of 1 *Matra* or *Akshara*. The *Suladi Sapta Talas* are represented in the traditions as follows and this representation is smoothly accommodated in the *Nava Gana* system. *Sapta Talas* are as follows: *Dhruva Tala*- IOII, *Matya*

Tala- IOI, *Roopaka Tala* (Carnatic)- OI, *Jhampa Tala*- IUO, *Triputa Tala*- IOO, *Ata Tala*- IIOO, and *Eka Tala* (Carnatic) - I. Same system is adopted to describe a *Tala* under every *Gana* in the following descriptions.

After this information some more specific information about the *Talas* is also provided. It includes the information about the total number of *Matras* in a *Tala*, number of *Vibhagas*, number of *Angas*, number of *Pratyangas*, and number of *Upangas* if any. This is the bare minimum information that is provided about all the *Talas* classified under the *Nava Gana* system. Apart from this information some more additional information about North Indian *Talas* is provided. It covers the structure of the signature *Anga* of a specific *Tala* along with the *Krama* type of the *Pratyangas* and the *Tala Bols*. This information is provided only for North Indian *Talas.* For Carnatic *Talas* this information is not provided because it was felt that some more research needs to be done in this regard. For the same reason information is not provided about the *Chapu Talas*, 72 *Melakarta Talas* and ancient *Talas*.

Tryashra Gana

North Indian *Talas*

Tala Name	*Khanda*	*Matra*	*Vibhaga*	*Anga*	*Pratyanga*	*Upanga*	Krama	Signature *Anga*
Dadara	II (3-3)	6	2	2	1	0	*Sarala*[3]	[[Sam], [Dha, Dhi, Na]]

Tryashra Gana

Suladi Sapta Talas

Name	Khanda	Matra	Vibhaga	Angas	Pratyanga	Upanga
Dhruva Tala	IOII (3-2-3-3)	12	3	3	1	1
Matya Tala	IOI (3-2-3)	8	2	2	1	1
Roopaka Tala (Carnatic)	OI (2-3)	5	1	1	1	1
Jhampa Tala	IUO (3-1-2)	6	1	1	1	2
Triputa Tala	IOO (3-2-2)	7	1	1	1	2
Ata Tala	IIOO (3-3-2-2)	10	2	2	1	2
Eka Tala (Carnatic)	I (3)	3	1	1	1	0

Chatarashra Gana

North Indian *Talas*

Tala Name	*Khanda*	*Matra*	*Vibhaga*	*Anga*	*Pratyanga*	*Upanga*	Krama	Signature *Anga*
Adda	II (4-4)	8	2	2	1	0	*Sarala* [4]	[[Sam], [Dha, Dhi, Dhagi, Dhin]]
Dhumali	II (4-4)	8	2	2	2	0	*Sarala* [2, 2]	[[Sam], [Dhin, Dhin, Dha, Dhin]]
Ekatala	III (4-4-4)	12	3	3	2	0	*Sarala* [2, 2]	[[Sam], [Dha, Tirkit, Dhin, Dhin]]
Kerava	II (4-4)	8	2	2	1	0	*Sarala* [4]	[[Sam], [Dha, Gi, Na, Ti]]
Tilwada (Type 1)	IIII (4-4-4-4)	16	2	4	1	0	*Sarala* [4]	[[Sam], [Dha, Dhin, Dhin, Dha]]
Trital or Teena Tala	IIII (4-4-4-4)	16	2	4	1	0	*Sarala* [4]	[[Sam], [Dha, Dhin, Dhin, Dha]]

Chatarashra Gana

Suladi Sapta Talas

Name	Khanda	Matra	Vibhaga	Angas	Pratyanga	Upanga
Dhruva Tala	IOII (4-2-4-4)	14	3	3	1	1
Matya Tala	IOI (4-2-4)	10	2	2	1	1
Roopaka Tala (Carnatic)	OI (2-4)	6	1	1	1	1
Jhampa Tala	IUO (4-1-2)	7	1	1	1	2
Triputa Tala	IOO (4-2-2)	8	1	1	1	2
Ata Tala	IIOO (4-4-2-2)	12	2	2	1	2
Eka Tala (Carnatic)	I (4)	4	1	1	1	0

Khanda Gana

North Indian *Talas*

Table to be continued

Tala Name	*Khanda*	*Matra*	*Vibhaga*	*Anga*	*Pratyanga*	*Upanga*	*Krama*	Signature *Anga*
Jhampa	II (5-5)	10	2	2	2	0	*Anuloma* [2, 3]	[[Sam], [Dhi, Na], [Dhi, Dhi, Na]]
Jhapatala	II (5-5)	10	2	2	2	0	*Anuloma* [2, 3]	[[Sam], [Dhi, Na], [Dhi, Dhi, Na]]

Khanda Gana

Suladi Sapta Talas

Name	Khanda	Matra	Vibhaga	Angas	Pratyanga	Upanga
Dhruva Tala	IOII (5-2-5-5)	17	3	3	1	1
Matya Tala	IOI (5-2-5)	12	2	2	1	1
Roopaka Tala (Carnatic)	OI (2-5)	7	1	1	1	1
Jhampa Tala	IUO (5-1-2)	8	1	1	1	2
Triputa Tala	IOO (5-2-2)	9	1	1	1	2
Ata Tala	IIOO (5-5-2-2)	14	2	2	1	2
Eka Tala (Carnatic)	I (5)	5	1	1	1	0

Tryashra Guru Gana

No North Indian *Talas* for this *Gana*

Tryashra Guru Gana

Suladi Sapta Talas

Name	Khanda	Matra	Vibhaga	Angas	Pratyanga	Upanga
Dhruva Tala	IOII (6-2-6-6)	20	3	3	1	1
Matya Tala	IOI (6-2-6)	14	2	2	1	1
Roopaka Tala (Carnatic)	OI (2-6)	8	1	1	1	1
Jhampa Tala	IUO (6-1-2)	9	1	1	1	2
Triputa Tala	IOO (6-2-2)	10	1	1	1	2
Ata Tala	IIOO (6-6-2-2)	16	2	2	1	2
Eka Tala (Carnatic)	I (6)	6	1	1	1	0

Mishra Gana

North Indian *Talas*

Tala Name	*Khanda*	*Matra*	*Vibhaga*	*Anga*	*Pratyanga*	*Upanga*	*Krama*	Signature *Anga*
Dipachandi	I (7)	14	2	2	2	0	*Anuloma* [3, 4]	[[Sam], [[Dha, Dhin, Avagraha], [Dha, Dha, Dhin, Avagraha]]
Jhumara	II (7-7)	14	2	2	2	0	*Anuloma* [3, 4]	[[Sam], [Dha, Dha, Tirkit, Dhin, Dhin, Dhagi, Tirkit]]

Mishra Gana

Suladi Sapta Talas

Name	Khanda	Matra	Vibhaga	Angas	Pratyanga	Upanga
Dhruva Tala	IOII (7-2-7-7)	23	3	3	2	1
Matya Tala	IOI (7-2-7)	16	2	2	2	1
Roopaka Tala (Carnatic)	OI (2-7)	9	1	1	2	1
Jhampa Tala	IUO (7-1-2)	10	1	1	2	2
Triputa Tala	IOO (7-2-2)	11	1	1	2	2
Ata Tala	IIOO (7-7-2-2)	18	2	2	2	2
Eka Tala (Carnatic)	I (7)	7	1	1	2	0

Chatarashra Guru Gana

North Indian *Talas*

Tala Name	*Khanda*	*Matra*	*Vibhaga*	*Anga*	*Pratyanga*	*Upanga*	*Krama*	Signature *Anga*
Tilwada (Type 2)	II (8-8)	16	2	2	3	0	*Anuloma* [1,3, 4]	[[Sam], [Dha], [Tirkit, Dhin, Dhin], [Dha, Dha, Dhin, Dhin]]

Chatarashra Guru Gana

Suladi Sapta Talas

Name	Khanda	Matra	Vibhaga	Angas	Pratyanga	Upanga
Dhruva Tala	IOII (8-2-8-8)	26	3	3	3	1
Matya Tala	IOI (8-2-8)	18	2	2	3	1
Roopaka Tala (Carnatic)	OI (2-8)	10	1	1	3	1
Jhampa Tala	IUO (8-1-2)	11	1	1	3	2
Triputa Tala	IOO (8-2-2)	12	1	1	3	2
Ata Tala	IIOO (8-8-2-2)	20	2	2	3	2
Eka Tala (Carnatic)	I (8)	8	1	1	3	0

Sankirna Gana

No North Indian *Talas* for this *Gana*

Sankirna Gana

Suladi Sapta Talas

Name	Khanda	Matra	Vibhaga	Angas	Pratyanga	Upanga
Dhruva Tala	IOII (9-2-9-9)	29	3	3	3	1
Matya Tala	IOI (9-2-9)	20	2	2	3	1
Roopaka Tala (Carnatic)	OI (2-9)	11	1	1	3	1
Jhampa Tala	IUO (9-1-2)	12	1	1	3	2
Triputa Tala	IOO (9-2-2)	13	1	1	3	2
Ata Tala	IIOO (9-9-2-2)	22	2	2	3	2
Eka Tala (Carnatic)	I (9)	9	1	1	3	0

Khanda Guru Gana

No North Indian *Talas* for this *Gana*

Khanda Guru Gana

Suladi Sapta Talas

Name	Khanda	Matra	Vibhaga	Angas	Pratyanga	Upanga
Dhruva Tala	IOII (10-2-10-10)	32	3	3	3	1
Matya Tala	IOI (10-2-10)	22	2	2	3	1
Roopaka Tala (Carnatic)	OI (2-10)	12	1	1	3	1
Jhampa Tala	IUO (10-1-2)	13	1	1	3	2
Triputa Tala	IOO (10-2-2)	14	1	1	3	2
Ata Tala	IIOO (10-10-2-2)	24	2	2	3	2
Eka Tala (Carnatic)	I (10)	10	1	1	3	0

Prakirna Gana

North Indian *Talas*

Tala Name	*Khanda*	*Matra*	*Vibhaga*	*Anga*	*Pratyanga*	*Upanga*	*Krama*	Signature *Anga*
Roopaka	I (7)	7	1	1	3	0	*Viloma* [3, 2, 2]	[[Sam], [Dha, Dhi, Na], [Ti, Na], [Dhi, Na]]

Prakirna Gana

No *Suladi Sapta Talas* in the *Prakirna Gana*

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APPENDIX VI

Computational *Raga* Statistics till May 2023

Dr. Vinod Vidwans has developed an AI system called *AI-RagaGen*. This system is capable of computationally generating existing and all possible new *Ragas* based on GTIM. The statistical summary of the computationally generated *Ragas* is as follows.

Regular *Ragas*- *Sadharana Ragas* by *Vadi-Samvadi* pairs

SN	Vadi-Samvadi Pairs	Numbers
1	KRe-KDha	49
2	Re-Dha	147
3	Re-Pa	851
4	KGa-KNi	84
5	KGa-KDha	86
6	Ga-Ni	496
7	Ga-Dha	164
8	Ma-Sa	1741
9	Pa-Sa	2732
10	KDha-KGa	522
11	KDha-KRe	232
12	Dha-Ga	696
13	Dha-Re	169
	Total	**7969**

Regular *Ragas*- *Sadharana Ragas* by Categories

SN	*Raga* Category	Numbers
1	*Sampurna-Sampurna*	255
2	*Shadava-Shadava*	624
3	*Oudava-Oudava*	413
4	*Shadava-Sampurna*	1450
5	*Sampurna-Shadava*	955
6	*Oudava-Sampurna*	1586
7	*Sampurna-Oudava*	280
8	*Oudava-Shadava*	1021
9	*Shadava-Oudava*	354
10	Different *Varjya Swara Ragas* (*Shadava-Shadava*)	1031
	Total	**7969**

Different *Varjya Swara Ragas*- *Prakirna Ragas*

SN	Raga Category	Numbers
1	*Shadava-Shadava* Different *Varjya*	-
2	*Oudava-Oudava* Different *Varjya*	398
3	*Oudava-Shadava* Different *Varjya*	1082
4	*Shadava-Oudava* Different *Varjya*	210
	Total	**1690**

Regular *Ragas* = 7969

‘Multi-Dual’ *Swara Ragas*=902

Different *Varjya swara Ragas* = 1690

***Tri-Gandhar Ragas* (*Prakirna Ragas*) = 21**

***Chatuhswaradi Ragas*= 1208**

Total No. of *Ragas* = 11,790

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PART X
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The Music of Minds and Machines

A Deep Dive into the Generative Theory of Indian Music

About the Author

Dr. Vinod Vidwans, presently a professor at FLAME University, Pune, is a computational musicologist. He holds a Master's Degree in Design from the Industrial Design Center, IIT Bombay. He earned his PhD in Cognitive Philosophy from IIT Bombay. It was here that he first became enamoured with the possibilities of Computational Indian Music. This research in Indian Music has been a constant in his career in the decades since. He was a senior professor at the National Institute of Design Ahmedabad, heading the departments of New Media Design, User Interface Design and served as an Advisor for the Design Foundation program. He has also contributed to the development of the NCERT textbooks on Graphic Design for class XI and XII.

He has presented his work on Computational Indian Classical Music at various platforms such as India International Science Festival (IISF), India Science Festival, Vision India Foundation, New Delhi, Center for Mathematical Modeling and Simulation, Pune University to name a few.

Apart from his busy professional career, Dr. Vidwans has an affinity for the classical languages of India, with a special interest in Sanskrit.

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FLAME UNIVERSITY

The Music of Minds and Machines

A Deep Dive into the Generative Theory of Indian Music

Can the aesthetic experience of an Indian musical performance be formalized and replicated on a computer? That was the question that animated and sustained the years of research that led to the eventual development of the Generative Theory of Indian Music. The fruits of this long labor also include two Artificially Intelligent (AI) systems viz. AI-Raga and AI-Tala and few other smart systems. Though rooted in the ancient treatises, the theory takes a novel and foundational approach towards Indian Music.

The Theory attempts to unearth the harmonic bases of the Indian musical tradition and codifies them into the 'Laws of Musical Intelligence'. These along with some fundamental axioms combine and conjugate to spawn the fundamental scales and modes of Hindustani Music. The Theory then delves into the formation of the Ragas and their evolution which rather surprisingly has a computational dimension. It also explores the various factors involved in phrase generation, rendering, Vistara and performance of a Bandish. The latter part of the book is dedicated to the theory of rhythm or Tala. A Gana-Varga based classification system for Ragas and Talas is also developed and exposited.

It is to be hoped that this book sparks interest in those with a passion to uncover the logical foundations of art in general and music in particular. To that end, the author wishes the well-wishing adventurer in setting forth.

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