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STRUCTURE OF INDIAN RAGAS: AN INTERVAL-BASED APPROACH TO IDENTIFY *SHRUTIS*

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ABSTRACT

Traditional north and south Indian classical music is primarily raga based. Even compositions which are considered as *light classical* are based on some ragas. Considering the fact that Indian classical interval tuning is *just intonation* as opposed to *equal temperament* of western music, this article attempts to systematically identify the correct set of micro-tones, known as *Shrutis* for some selected *Ragas*. The adopted method is based on the ascending and descending structure of the *Ragas* as well as the predefined tonal centers of different ragas called *Vadi* and *Samvadi*. Taking few well-known Indian *Ragas* as examples, this article shows how these *Ragas* are formed out of a unique system which is based on the concepts of just intonation intervals.

KEYWORDS: Indian Classical Music, Indian Tuning System, Raga, Shrutis, Musicology

Throughout the human history, different civilization has invented various types of tuning systems for the purpose of making music. The underlying idea, nonetheless, is same in all those systems. The idea is to divide the continuous range of frequency in a number of discrete intervals. It is somewhat a matter of regret the response of the human brain to different discrete audible frequency is such that dividing a range of frequency into simple equal intervals does not make the intervals pleasant to human ears. Due to the formation of overlapping spectra, if the ratio of two frequencies is small fractions, the interval sound pleasant to human ears. Following this restriction, early practitioners of music have learnt to divide a range of frequencies in ways which are beneficial to produce compositions pleasant to human ears. Gradually, the musical scales of different civilizations have evolved following different unique paths. For example, western classical music, nowadays, has mostly adopted equal temperament scale which allows us to bypass the restriction imposed by nature to create music which are harmony-based i.e. where some combinations of multiple notes can be played simultaneously at the same time. While the *equal temperament* scale facilitates the creation of beautiful harmonic structures, this advantage comes at a cost. The inherent pleasantness of naturally occurring intervals, i.e. frequency ratios which are simple ratios (comprised of small round number as numerator and denominator), is compromised to some extent. Moreover, a lot of possible notes had to be discarded completely to fit a 12-note western scale. Interestingly, ancient Indian musicians have made another kind of compromise which is completely different from the compromise made to form the *equal-temperament* scale. They tried to retain as many notes as they can by inventing *Shrutis* or micro-tones. This liberty of having interesting intervals is expressed through different *Ragas*, the basis of Indian classical music. *Ragas* are predefined scales, along with predefined ascending and descending movements through which the beauty of different intervals are expressed by inventing interesting melodic patterns. The structure is also characterized by two tonal centers - called *Vadi* and *Samvadi*. The compromise made in such a system is that this system is inadequate to create complex harmonic structures. In view of this uniqueness of Indian classical music, we scientifically attempt to analyze raga structures based on musical intervals with the help of tonal centers, *Vadi* and *Samvadi* and attempt to come to a conclusion about the appropriate set of *Shrutis* for these *Ragas*.

Some recent attempts have been made to unravel the structure of the *Ragas* based on *Shrutis*. For example, Vidyadhar Oke has created a system which can be used to play all *Ragas* based on 22 *Shrutis* (http://www.22shruti.com, 2022). A list of shrutis for the important *Ragas* are also published. However, the system relied on the only a few intervals (much like Pythagorean Tuning which will be discussed later in Section-2) because it is primarily developed for free-reed keyboard instruments. Moreover, the important concept of the tonal centers, i.e. *Vadi* and *Samvadi* are missing in such a construction. Apart from this effort, there exists experimental objective studies which attempts to identify the *Shrutis* based on signal processing techniques from recorded renderings of *Ragas* performed by various artists (Datta *et al.*, 2003; Datta *et al.*, 2004). In some

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studies, recorded dataset of both instrumental and vocal raga excerpts are also used for tonic and *Shruti* identification (Pawar and Mahajan, 2019). However, none of these studies attempt to associate *Shrutis* to different *Ragas* based on predefined *Vadi-Samvadi* pair, and easy to identify intervals. In our belief, this is a first attempt to analyze *Ragas* in terms of intervals, *Vadi-Samvadi* combination of tonal centers and *Shrutis*.

MOTIVATION AND OBJECTIVE

The digital era has made possible the creation of a number of digital software and equipment related to music production. Aided by these recent advances, the music production has seen major changes in recent times. However, such impressive advancement is mostly around western equal temperament scale of discrete 12 notes. The lack of systematic study on the just-interval based Indian music scales has prevented similar advancement in the field of Indian classical music. For instance, there exists no software which can be used to produce and render a *Raga* digitally using different *Shrutis* and the concept of *Nadas* (continuous sliding from one *Shruti* to another). Systematic interval-based study and analysis of Indian *Ragas* would aid the technological advancement of Indian classical music. The starting point of such an effort might be the identification of correct set of frequencies or *Shrutis* associated with different *Ragas*, identification of required musical intervals which can be used to produce these *Shrutis*, and finally develop more understanding about the structure of different *Ragas.*

Objective of this study is, using basic musical intervals, explore the possible set of *Shruits* to identify the correct micro-tones and the interval patterns of few selected popular *Ragas* in a systematic manner. This analysis would be mostly aided by two important concepts - *Vadi* and *Samvadi* - two predefined important tonal centers associated with a *Raga*. We demonstrate when *Vadi-Samvadi* pair is considered along with just intonation intervals, it is possible to identify the correct set of *Shrutis* associated with a *Raga*.

Pythagorean Tuning

Similar to majority of the scales which are used today, Pythagorean tuning system is comprised of 12 notes. The corresponding frequency ratios of different notes are shown in Table 1 with the assumption of C being the reference note.

Table 1: Pythagorean Tuning System

C	C♯	D	E ♭	E	F	F♯	G	A ♭	A	B ♭	B
$\frac{1}{1}$	$\frac{256}{243}$	$\frac{9}{8}$	$\frac{32}{27}$	$\frac{81}{64}$	$\frac{4}{3}$	$\frac{1024}{729}$	$\frac{3}{2}$	$\frac{128}{81}$	$\frac{27}{16}$	$\frac{16}{9}$	$\frac{243}{128}$

This tuning system might seem puzzling initially. Some of the ratios are anything but simple (i.e. comprised of small round number as numerator and small round number as denominator). But the construction process involves the use of simple ratios. Musical intervals are directly associated with these simple ratios. Before explaining the construction process, let us define a few simple ratios or intervals which are frequently used to construct such scales. These ratios are easily identifiable by trained ears. These are listed in Table 2. The level of difficulty to identify these intervals are also shown. The easy ones can be easily identified. The moderate ones perhaps require additional effort and training to identify.

It may be noted that ascending perfect fifth $\left(\frac{3}{2}\right)$, descending perfect fifth $\left(\frac{2}{3}\right)$, along with the concept of octave $\left(\frac{2}{1}\right)$, can give rise to perfect fourths, i.e. $\frac{4}{3}$ and $\frac{3}{4}$. This process is called inversion. To elaborate, we consider the range between a frequency $\frac{1f}{1}$ and its octave $\frac{2f}{1}$. If we mark $\frac{3f}{2}$ as fifth, the interval which is left between $\frac{3f}{2}$ and $\frac{2f}{1}$ is $\frac{4}{3}$ with respect to fifth. In other words, the ratio between the octave and fifth becomes $\frac{4}{3}$. This can be seen as $\frac{3f}{2} \times \frac{4}{3} = \frac{2f}{1}$. That is to say, given a frequency, f, if we ascend to a fifth, then if we again ascend a fourth of that fifth, we reach to the octave of f, i.e. $2f$. Similarly, consider the descending range between f and $\frac{f}{2}$. Note that f is octave of $\frac{f}{2}$. If we descend a *descending perfect fifth* $\left(\frac{2}{3}\right)$, and again descend a $\frac{3}{4}$ of that frequency, we reach $\frac{f}{2}$ (in other words, $\frac{2f}{3} \times \frac{3}{4} = \frac{1f}{2}$).

Table 2: Common Intervals and Associated Ratios

Name of Interval	Numeric Ratio	Identifiability
Ascending octave	$\frac{2}{1}$	Easy
Descending octave	$\frac{1}{2}$	Easy
Ascending perfect fifth	$\frac{3}{2}$	Easy
Descending perfect fifth	$\frac{2}{3}$	Easy
Ascending perfect fourth	$\frac{4}{3}$	Easy
Descending perfect fourth	$\frac{3}{4}$	Easy
Ascending perfect major third	$\frac{5}{4}$	Moderate
Descending perfect major third	$\frac{4}{5}$	Moderate
Ascending perfect major sixth	$\frac{5}{3}$	Moderate
Descending perfect major sixth	$\frac{3}{5}$	Moderate
Ascending perfect minor third	$\frac{6}{5}$	Moderate
Descending perfect minor third	$\frac{5}{6}$	Moderate

The idea of Pythagorean Tuning system is to use four intervals, $\frac{3}{2}, \frac{2}{3}, \frac{4}{3}, \frac{3}{4}$, to construct the entire scale. Starting from C, the scale is constructed by moving six steps (around the circle of fifths) to the left and six to the right to discover new notes. Each step consists of a multiplication of the previous pitch by one of these four ratios.

There exist similar other tuning techniques as well such as Five limit tuning which relies on similar concepts. One advantage of such a tuning system is musicians can tune by ear given the construction is based on easily identifiable intervals such as $\frac{3}{2}$ or $\frac{4}{3}$. In a movable fret instrument, such as Sitar, one can start with any pitch f, and gradually tune all 12 notes based on this starting point. For example, we will first identify octave $2f$. Then, we will identify $\frac{3f}{2}$. After that, we will identify $\frac{9f}{8}$, then $\frac{27f}{16}$ and so on.

One problem in Pythagorean tuning is that such tuning does not work with all the keys. As a consequence, creating harmonic structure becomes problematic. To overcome this problem, *equal temperament tuning*, which is now widely used in western music, is created. But apart from this problem, there exists another shortcoming with Pythagorean Tuning. The shortcoming is Pythagorean tuning has to throw away several "*good"* frequency intervals to choose only 12 notes out of several possible options. For example, a note $\frac{5f}{4}$ is expected to be pleasant to human ears with respect to reference f, but Pythagorean tuning does not include it. Indian classical music system tuning has solved this problem by introducing *Shrutis*. By sacrificing on the harmonic structure, Indian classical music system has been able to create complex melodic structures by using various possible combinations of "*good"* intervals inside different *Ragas*.

Indian Tuning System: *Shrutis*

Indian classical tuning system follows similar concept as that of *Pythagorean tuning system*. Only difference is, the number of possible notes is larger than 12. One might think the use of large number of possible notes increases the complexity to a great extent and it is practically impossible to master it even at a moderate level. The truth is, although there exists a large number of possible notes, a particular *Raga* consists of just a set of few notes and intervals. It is sufficient to understand the interval patterns and interaction of few notes associated with a *Raga* to play and enjoy it. For a performer, just right kind of tuning can solve a lot of difficulties. Indian classical music has evolved in a unique way. The lack of

systematic studies on appropriate tuning system corresponding to different *Ragas* seems to have created some confusion. There is no doubt expert performers use frequencies and intervals in an appropriate manner, but how they manage to learn such a vast number of intervals might seem beyond explanation considering there is no book or systematic study material to reproduce such beautiful melodic structures. The answer to this interesting question lies in the method of learning and the choice of instruments. If we carefully observe, the Indian classical instruments are mostly either fret-less, or flexible in fret, that is pitch can be changed (bended) in and around a note. The example of the first kind is *Sarod*, and the example of second kind is *Sitar*. This flexibility allows a learner to be able to experiment with different possible notes near a "*guess note*" or "*crude note*". By playing a single melodic pattern several times, and by experimenting with a set of possible "*crude notes*", a learner gradually develops the perfect combination of intervals to produce melodic structures that are associated with a *Raga* and at the same time pleasant to hear. The process is aided by the teacher, called "*Gurus*", who already has mastered the correct intervals and melodic patterns and the student try to imitate the exact frequency produced by the teacher. In this way, years of learning can make someone competent enough to reproduce correct combination of intervals associated with a *Raga* structure.

To understand the *Raga* structure, we will start with a list of possible micro-tones and systematically unravel the correct interval pattern in between them. In this process, we would identify the correct scale. One such possible list of ratios is given in Table-3. There are technical names of each of these micro-tones or *Shrutis*, but for the sake of clarity we omit them here and adopt an alphabetical notation system for the "*crude notes*" near a *Shruti*. Another point to note is unlike notes in western music such as C, D etc., in Indian system, the frequency of reference is not fixed. Any frequency can be taken as the reference note, *Saraj* (Sa) and all other notes will be relative to this reference note. That is, the ratios associated with Shrutis are relative to *Saraj* (Sa). Somehow, the difference between a person having a relative pitch and a person having perfect pitch is not recognized by Indian classical music. There is no doubt some performers are perfect pitch, but the system itself is based on relative pitch. For demonstration purposes we associate C with Saraj (Sa), much like a *fixed-do solfege*.

Table 3: Indian Tuning with Different *Shrutis*

Crude Note (Western)	**C**	**D ♭**	**D**	**E ♭**	**E**	**F**	**F♯**	**G**	**A ♭**	**A**	**B ♭**	**B**
Initials of Indian Notes	Sa	Komal Re	Re	Komal Ga	Ga	Ma	Tivra Ma	Pa	Komal Dha	Dha	Komal Ni	Ni
Notation	(S)	(r)	(R)	(g)	(G)	(m)	(M)	(P)	(d)	(D)	(n)	(N)
Set-1	$\frac{1}{1}$	$\frac{256}{243}$	$\frac{9}{8}$	$\frac{32}{27}$	$\frac{81}{64}$	$\frac{4}{3}$	$\frac{45}{32}$	$\frac{3}{2}$	$\frac{128}{81}$	$\frac{27}{16}$	$\frac{16}{9}$	$\frac{243}{128}$
		$\frac{16}{15}$	$\frac{10}{9}$	$\frac{6}{5}$	$\frac{5}{4}$	$\frac{27}{20}$	$\frac{729}{512}$		$\frac{8}{5}$	$\frac{5}{3}$	$\frac{9}{5}$	$\frac{15}{8}$
Set-2				$\frac{19}{16}$	$\frac{9}{7}$		$\frac{64}{45}$		$\frac{11}{7}$	$\frac{12}{7}$		

It can be seen in Table-3, except for F♯, all the frequencies of original Pythagorean tuning system are retained in *Shruti*-based Indian tuning system. Apart from perfect fifth and perfect fourth, two other important intervals are major third $\left(\frac{5}{4}\right)$, major sixth $\left(\frac{5}{3}\right)$, and minor third $\left(\frac{6}{5}\right)$. All these small intervals can be learned and used to create the *Shrutis* following principle of Pythagorean construction. The process is straightforward. It requires the multiplication of simple interval ratios (Bansod and Sharma, 2019). It may be noted Table-3 does not show the exhaustive list of possible ratios. Different schools have developed their own set of intervals, although the basic idea is same - that is to use small set of intervals to produce different *Raga* scales. In Set-2 of Table-3, some other possibilities are listed.

ANALYSIS OF FEW RAGAS

In this section, we will systematically analyze few popular *Ragas* and attempt to come to a conclusion regarding the correct micro-tones (*Shrutis*) associated that *Raga*. We will use North Indian classical (popularly called as *Hindustani* classical) music convention for the *Raga* names and their ascending and descending characters. Our analyses are interval based, i.e. we will consider ratio of frequencies as a basis of our analysis. It may be noted, a ratio can mean two things. It might mean an interval, or it might mean a particular frequency or

Shruti. In the second case, the ratio is referring to the interval between the reference note Sa (S) and the concerned *Shruti*. To distinguish these two meanings, we would write the ratio to indicate intervals, and we will use the symbol f to indicate *Shrutis*. For instance, *Shrutis* will be indicated as $\frac{1f}{1}$, $\frac{256f}{243}$, $\frac{16f}{15}$ etc. Given a note S, its upper octave would be denoted by S'; and the lower octave would be denoted by S.

Raga Bhairavi

This morning raga has *Vadi* as **m**, Samvadi as **S**. The ascending and descending structure is as follows.

Ascending: **S - r - g - m - P - d - n - S'** (Octave of S)

Descending: **S' - n - d - P - m - g - r - S**

Vadi : **m**

Samvadi : **S**

Some typical characteristic of this raga is, in ascending, often **r** and **P** are skipped. In descending, often **g** is skipped. Given these characteristics, we will try to identify the possible *Shrutis*.

Fixing the m trivial. As S is *Samvadi*, and *m* is *Vadi*, they are most likely to be separated by simple interval. The reference S is $\frac{1f}{1}$. We ascend a fourth from S to reach to m. Therefore, m is possibly $\frac{4f}{3}$. Now if m is fixed as $\frac{4f}{3}$, we might attempt to identify the correct *Shruti* for n. The idea is simple, from *Vadi* or *Samvadi*, we need to have as few steps with easily identifiable intervals as possible. Possible options for n are $\frac{16f}{9}$ and $\frac{9f}{5}$. We can easily ascend a fourth from m and reach $\frac{16f}{9}$. That is $\frac{4f}{3} \times \frac{4}{3} = \frac{16f}{9}$. On the other hand, if n was $\frac{9f}{5}$, then we must ascend $\frac{27}{20}$ from m, which is a worse choice. Therefore, we take n as $\frac{16f}{9}$. Now let us consider r. We know, during descending, g is often skipped. Therefore, r comes right after m during descend. Moreover, m is *Vadi*. Therefore, there must be some simple interval between m and r. We have two options for r, $\frac{256f}{243}$ and $\frac{16f}{15}$. We can attain $\frac{16f}{15}$ from m $\left(\frac{4f}{3}\right)$ following $\frac{4f}{3} \times \frac{4}{5} = \frac{16f}{15}$. If r were $\frac{256f}{243}$, the required interval (ratio) would have been $\frac{64}{81}$, rather a difficult to identify interval. Therefore, r may be fixed at $\frac{16f}{15}$. The *Shrutis* identified so far are shown in Table-4. We additionally filled the ratio for P given it has only one option.

Table 4: Raga Bhairavi *Shrutis*

Crude Note (Western)	**C**	**D ♭**	**E ♭**	**F**	**G**	**A ♭**	**B ♭**
Initials of Indian Notes	Sa	Komal Re	Komal Ga	Ma	Pa	Komal Dha	Komal Ni
Notation	(S)	(r)	(g)	(m)	(P)	(d)	(n)
Identified so far	$\frac{1f}{1}$	$\frac{16f}{15}$		$\frac{4f}{3}$	$\frac{3f}{2}$		$\frac{16f}{9}$

Now, let us consider g. It has been mentioned before that in ascending, often r is skipped. That means, during ascending, g comes right after *Samvadi*, S. This indicates perhaps the interval (ratio) of g is related to *Samvadi* more closely than to *Vadi*. Two candidates for g are $\frac{6f}{5}$ and $\frac{32f}{27}$. Here, the decision regarding g is a difficult one. On one hand, we can use directly ascend an interval $\frac{6f}{5}$ (which perhaps is not an easily identifiable interval) from *Samvadi*, S to reach to the first option; but on the other hand, we can descend a fifth $\left(\frac{2}{3}\right)$ from n to reach to the second option. Considering the raga structure, transition from n to g is perhaps not that frequent. Therefore, we identify the first option as more probable one. For d, we have two candidates, $\frac{128f}{81}$ and $\frac{8f}{5}$. It has been mentioned that in ascending, often P is skipped. We can reach to $\frac{8f}{5}$ from m by ascending a perfect minor third $\left(\frac{6}{5}\right)$. So, one possible set of *Shrutis* for this *Raga* might be as is given in Table 5.

Table 5: Raga Bhairavi *Shrutis* (Complete)

Crude Note (Western)	**C**	**D ♭**	**E ♭**	**F**	**G**	**A ♭**	**B ♭**
Initials of Indian Notes	Sa	Komal Re	Komal Ga	Ma	Pa	Komal Dha	Komal Ni
Notation	(S)	(r)	(g)	(m)	(P)	(d)	(n)
Shrutis	$\frac{1f}{1}$	$\frac{16f}{15}$	$\frac{6f}{5}$	$\frac{4f}{3}$	$\frac{3f}{2}$	$\frac{8f}{5}$	$\frac{16f}{9}$

The tuning would be as follows. First we fix S, and P. Then we proceed to tune m by ascending from S an interval equal to perfect fifth. Then we tune n by ascending another perfect fifth from m. Then we tune r by descending $\frac{4}{5}$ from m. The interval $\frac{4}{5}$ is the most common just interval for descending major third (Refer to Table-2). In other words, we need to find a *Shruti* for r such that we can ascend a major third amount from that *Shruti* to reach to m. Finally, we tune g and d by ascending $\frac{5}{6}$ amount from *Samvadi* (S) and *Vadi* (m) respectively.

Raga Darbari

This raga has *Vadi* as **R**, *Samvadi* as **P**. The ascending and descending structures are as follows.

Ascending: **S - R - g, g - m - P - d - n - S'**

Descending: S' - d - n - P - m - P - g, g - m - R, S

Vadi : **R**

Samvadi : **P**

As shown, ascending and descending structure is not straight. The movements have some complexities. In our analysis, we first fix *Samvadi* P. We have only one option on that note. Then we establish the relation between *Samvadi* (P), and *Vadi* (R). We descend from P a descending fourth amount to get *Vadi* (R). Like previous example, here also *Vadi* and *Samvadi* are separated by a fourth. If from P, we descend a perfect fifth, we reach to S. From there, a perfect fourth will lead us to m $\left(\frac{4f}{3}\right)$. Similar to the previous example, we can reach to n by ascending another perfect fourth. So, we fix the *Shruti* for n as $\frac{16f}{9}$. From n, if we descend one descending perfect fifth $\left(\frac{2}{3}\right)$, we reach to $\frac{32f}{27}$, one of the possible candidate for g. Note that, it is the famous *Ati-Komal Gandhar* (Extra-Flat Gandhar) of raga Darbari - a distinct feature of this Raga (Ramanathan, 2009). From g, we ascend another perfect fourth $\left(\frac{4}{3}\right)$ to reach to d $\left(\frac{128f}{81}\right)$. In this way, the construction of entire scale may be completed.

Table 6: Raga Darbari *Shrutis*

Crude Note (Western)	**C**	**D**	**E ♭**	**F**	**G**	**A ♭**	**B ♭**
Initials of Indian Notes	Sa	Re	Komal Ga	Ma	Pa	Komal Dha	Komal Ni
Notation	(S)	(R)	(g)	(m)	(P)	(d)	(n)
Shrutis	$\frac{1f}{1}$	$\frac{9f}{8}$	$\frac{32f}{27}$	$\frac{4f}{3}$	$\frac{3f}{2}$	$\frac{128f}{81}$	$\frac{16f}{9}$

So, the steps of constructing the scale are

1. **P** → (descending fourth) → **R**
2. **P** → (descending fifth) → **S**
3. **S** → (ascending fourth) → **m**
4. **m** → (ascending fourth) → **n**
5. **n** → (descending fifth) → **g**
6. **g** → (ascending fourth) → **d**

Note the difference of construction between the two ragas described so far. In the case of raga *Bhairavi*, we relied on slightly odd intervals such as major and minor thirds. On the other hand, for *Darbari*, we only used perfect fourth and fifth to construct the entire scale.

Raga Bhairav

Raga *Bhairav* has *Vadi* as **d**, *Samvadi* as **r**. The ascending and descending structures are as follows.

Ascending: **S - r - G - m - P - d - N - S'**

Descending: S' - N - d - P - m - G - r - S

Vadi : **d**

Samvadi : **r**

The *Vadi-Samvadi* combination, d and r has two possible candidates : $\left(\frac{128f}{81}, \frac{256f}{243}\right)$ and $\left(\frac{8f}{5}, \frac{16f}{15}\right)$. In both the cases, the candidate *Shrutis* for these two notes are separated by a *perfect fifth*. Any other possible combinations cannot provide such desirable interval separation. Now, to choose between these two cadidates, we take a new approach. We inspect the structure of the *raga*. One most common movement is : G - m - d - d - P, G - m - R - R - S. This pattern indicates that *Vadi*, d is related with P in the same manner as *Samvadi*, R, is related with S. Fortunately, both P and S are associated with only one candidate *Shrutis*. Therefore, we can conclude the pair $\left(\frac{8f}{5}, \frac{16f}{15}\right)$ is more appropriate for d and r. The reason is, if we choose these *Shrutis*, d to P interval becomes same as the interval of R to S ($=\frac{16}{15}$). So we fixed d as $\frac{8f}{5}$ and R as $\frac{16f}{15}$. From d, if we descend one octave, we reach to d, i.e. $\frac{4f}{5}$. From there, we can take two ascending steps of $\frac{5}{4}$ to reach to S and G respectively. So, we fix the *Shruti* for G as $\frac{5f}{4}$. From G, we can ascend a fifth to get N as $\frac{15f}{8}$. Finally, from S, we can ascend a perfect fourth to get m. m can also be identified by ascending $\frac{5}{4}$ from r. So, the *Shruti* identification process for this *Raga* is as follows (the *Shrutis* for all the notes are shown in Table 7):

1. Find a note on lower octave, from where a major third interval ascend $\left(\frac{5}{4}\right)$ can take us to the reference note **S** $\left(\frac{1f}{1}\right)$. Designate this note as lower octave **d** $\left(\frac{4f}{5}\right)$.

2. Find the upper octave **d** $\left(\frac{8f}{5}\right)$ by moving an octave.

3. **d** → (descending fifth) → **r**

4. **S** → (ascending major third) → **G**

5. **G** → (ascending fifth) → **N**

6. **S** → (perfect fourth) → **m** [alternatively **r** → (ascending major third) → **m**]

Table 7: Raga Bhairav *Shrutis*

Crude Note (Western)	**C**	**D ♭**	**E**	**F**	**G**	**A ♭**	**B**
Initials of Indian Notes	Sa	Komal Re	Ga	Ma	Pa	Komal Dha	Ni
Notation	(S)	(r)	(G)	(m)	(P)	(d)	(N)
Shrutis	$\frac{1f}{1}$	$\frac{16f}{15}$	$\frac{5f}{4}$	$\frac{4f}{3}$	$\frac{3f}{2}$	$\frac{8f}{5}$	$\frac{15f}{8}$

Raga Bhimpalasi

Raga Bhimpalasi has *Vadi* as **m**, *Samvadi* as **S**. The ascending and descending structures are as follows.

Ascending: **n - S - g - m - P - n - S'**

Descending: S' - n - D - P - m - g - R - S

Vadi : **m**

Samvadi : **S**

Out of all the *Shruti* candidates for m, the clear winner is $\frac{4f}{3}$, because the *Samvadi* for this *Raga* is S. Placing the Shruti of m on $\frac{4f}{3}$ makes *Vadi* and *Samvadi* to be separated by an easily identifiable *perfect fourth* interval.

From *Vadi*, m, we can ascend a *perfect fourth* to reach to $\frac{16f}{9}$. This settles the question regarding the *Shruti* of n. Note that, it is the famous *Ati-Komal Nishad* (Extra-Flat Ni) of raga *Bhimpalasi* - a distinct feature of this *Raga* (Ramanathan, 2009). Unlike majority of the Ragas, the ascending of which normally starts from the reference note, S, the ascending of *Bhimpalasi* starts from lower octave, n. It might be concluded this note is an important one for this raga. n is one octave lower than n, therefore n can be set at $\frac{8f}{9}$. From n, we can make a descend of perfect fifth $\left(\frac{2}{3}\right)$, to come to g $\left(\frac{32f}{27}\right)$. It might be noted R and D are skipped during ascending. For (R, D) pair, we identify two possible candidates: $\left(\frac{9f}{8}, \frac{27f}{16}\right)$ and $\left(\frac{10f}{9}, \frac{5f}{3}\right)$. In both the cases, the *Shrutis* for R and D are separated by a *perfect fifth*. If we choose the pair $\left(\frac{9f}{8}, \frac{27f}{16}\right)$, then intervals between S and g, and between R and m, becomes same ($= \frac{32}{27}$). Additionally, intervals between m and P, and between P and D become same ($= \frac{9}{8}$). To identify the *Shruti* for R, we may descend a *perfect fourth* from P. From R, if we ascend a *perfect fifth*, we reach D. So, the tuning or the formation of the scale may be as follows:

1. **S** → (ascending perfect fourth) → **m**

2. **m** → (ascending perfect fourth) → **n**

3. **n** → (descending octave) → **n**

4. **n** → (descending perfect fifth) → **g**

5. **P** → (descending perfect fourth) → **R**

6. **R** → (ascending perfect fifth) → **D**

It might be noted the *Shruti* for R can be found in another way. If we take two consecutive ascending perfect fifth $\left(\frac{3}{2}\right)$ step from reference note S, we will reach to $\frac{9f}{4}$ which is R'. From R', if we descend one octave lower, we can find R ($\frac{9f}{8}$). The possible set of *Shrutis* for this raga, as identified by this analysis, is shown in Table 8.

Table 8: Raga Bhimpalasi *Shrutis*

Crude Note (Western)	**C**	**D**	**E ♭**	**F**	**G**	**A**	**B ♭**
Initials of Indian Notes	Sa	Re	Komal Ga	Ma	Pa	Dha	Komal Ni
Notation	(S)	(R)	(g)	(m)	(P)	(D)	(n)
Shrutis	$\frac{1f}{1}$	$\frac{9f}{8}$	$\frac{32f}{27}$	$\frac{4f}{3}$	$\frac{3f}{2}$	$\frac{27f}{16}$	$\frac{16f}{9}$

Raga Yaman

Raga Yaman is an early night *Raga*. This is one of the most important *Ragas* in Indian classical music traditions. Often, students start their learning using this *Raga*. It has *Vadi* as **G**, *Samvadi* as **N**. The ascending and descending structures are as follows.

Ascending: **N - R - G - M - P - D - N - S'**

Descending: S' - N - D - P - M - G - R - S

Vadi : **G**

Samvadi : **N**

We start with *Vadi* (G) and *Samvadi* (N) combination. It requires some effort to identify the correct intervals for this raga as none of the two *single-Shruti* notes, S and P are either *Vadi* or *Samvadi*. *Vadi* (G) and *Samvadi* (N) pair has possible combinations i) $\left(\frac{81f}{64}, \frac{243f}{128}\right)$ ii) $\left(\frac{5f}{4}, \frac{15f}{8}\right)$. Both are separated by an interval of *perfect fifth*, $\frac{3}{2}$. All other possible *Shruti* combinations require non easily identifiable intervals. Now, let us start adding notes to these two possible combinations. We start with M, a distinct note which is very important for this *Raga*. If we choose the first combination for *Vadi* and *Samvadi*, then M might be $\frac{729f}{512}$, because choosing this *Shruti* for M would place M at an interval of $\frac{4}{3}$ from *Samvadi* N. On the other hand, for the second combination, Shruti for M is possibly $\frac{45f}{32}$, similarly having an interval of $\frac{4}{3}$ with *Samvadi*, N. Therefore, we begin with two sets of possible candidates for G, N and M. They are $\left(\frac{81f}{64}, \frac{243f}{128}, \frac{729f}{512}\right)$ and $\left(\frac{5f}{4}, \frac{15f}{8}, \frac{45f}{32}\right)$. For both set of candidates, the first two notes are at an interval of perfect fifth $\left(\frac{3}{2}\right)$. The last two notes are at an interval of descending perfect fourth $\left(\frac{3}{4}\right)$. We now attempt to add notes in these two possible set of candidate *Shrutis* in the hope of identifying the correct set of Shrutis for all the notes. Looking at the candidates for R (i.e. $\frac{10f}{9}$ and $\frac{9f}{8}$), it is evident $\frac{10f}{9}$ does not produce favourable (easy to identify) interval with either *Vadi* or *Samvadi*. Whereas, the other candidate, $\frac{9f}{8}$, produces an interval of $\frac{5}{3}$ with the *Shruti* for *Samvadi*, N $\left(\frac{15f}{8}\right)$ in the second set. If we select this candidate, then we can have two intervals of $\frac{5}{3}$. One from S to D, and another from R to N as presented in Table 9.

Table 9: Raga Yaman *Shrutis*

Crude Note (Western)	**C**	**D**	**E**	**F♯**	**G**	**A**	**B**
Initials of Indian Notes	Sa	Re	Ga	Tivra Ma	Pa	Dha	Ni
Notation	(S)	(R)	(G)	(M)	(P)	(D)	(N)
Shrutis	$\frac{1f}{1}$	$\frac{9f}{8}$	$\frac{5f}{4}$	$\frac{45f}{32}$	$\frac{3f}{2}$	$\frac{5f}{3}$	$\frac{15f}{8}$

Note the presence of different types of intervals such as $\frac{3}{2}$ (*Vadi*-*Samvadi*), $\frac{4}{3}$ (*Vadi*-D; M-*Samvadi*), $\frac{5}{4}$ (S-*Vadi*), $\frac{5}{3}$ (R-*Samvadi*; S-D). Perhaps the presence of all these basic intervals makes this raga ideal for the starting point of learning Indian classical music. For this reason, this raga is also believed to be one of the difficult *Ragas* as rendering all these intervals with perfection requires experience and competence.

Raga Malkauns

Raga *Malkauns* has a pentatonic scale. It has *Vadi* as **m**, Samvadi as **S**. The ascending and descending structures are as follows.

Ascending: **N - S - g - m - d - n - S'**

Descending: **S' - n - d - m - g - S**

Vadi : **m**

Samvadi : **S**

Reaching to a definitive conclusion about this *Raga* is somewhat difficult. We list three possible candidates for the *Shrutis* associated this *Raga* in Table 10.

Table 10: Raga Malkauns Possible set of *Shrutis*

Crude Note (Western)	**C**	**E ♭**	**F**	**A ♭**	**B ♭**
Initials of Indian Notes	Sa	Komal Ga	Ma	Komal Dha	Komal Ni
Notation	(S)	(g)	(m)	(d)	(n)
Possible *Shrutis -A*	$\frac{1f}{1}$	$\frac{32f}{27}$	$\frac{4f}{3}$	$\frac{128f}{81}$	$\frac{16f}{9}$
Possible *Shrutis -B*	$\frac{1f}{1}$	$\frac{6f}{5}$	$\frac{27f}{20}$	$\frac{8f}{5}$	$\frac{9f}{5}$
Possible *Shrutis -C*	$\frac{1f}{1}$	$\frac{6f}{5}$	$\frac{4f}{3}$	$\frac{8f}{5}$	$\frac{9f}{5}$

In all these three possibilities, interval between g and d is a *perfect fourth*, and interval between g and n is a *perfect third*. In the first two cases, interval between *Vadi*, m and n is *perfect fourth*. In Possibility-A and Possibility-C, interval between *Vadi* and *Samvadi* is *perfect fourth*. In Possibility-B and Possibility-C, the intervals are overall simple. Considering all the advantages and disadvantages, we postulate Possibility-C might be a probable choice. Additionally, some schools in Indian Classical Music believes that *Shrutis* associated with n of *Raga Malkauns* and *Raga Bhimpalasi* are different. If this belief is true, then possibility-A seems unlikely as we already identified the *Shruti* of n of *Raga Bhimpalasi* as $\frac{16f}{9}$ (refer to Table-8).

We conclude this section by mentioning that the approaches adopted here to identify the correct *Shrutis* can be extended to any *Raga*. This approach is a powerful one, as following similar logic, we can even attempt to construct new *Ragas* or invent new shades of the existing *Ragas*.

DISCUSSION

The possible *Shrutis* which are shown to be associated with the ragas, described in this article, might be subjective in nature. It is possible that some schools might interpret a raga differently from what is described in this article. Adaptation of a different set of *Shrutis* other than what is described here might reveal a different shade of the Raga. There are instances of a competent performer playing five different shades *Shrutis* of **d** associated with five different *Ragas* (Van der Meer and Rao, 2009).

Different schools might adopt different *Shruti* sets for a given *Raga*. In spite of this possible disagreement regarding the exact placement of *Shrutis* associated with a particular raga, the basic principle described in this article remains the same. Those are, *Vadi* and *Samvadi* are separated by simple easy to recognize intervals such as *perfect fourth* or *perfect fifth*. Additionally, the entire scale can be developed which is congruent to the selection of *Vadi* and *Samvadi*. What we would like to emphasize is the construction process of different *Raga* scales following simple steps using easily identifiable intervals as described in this article. It is the

vast options to select micro-tones and the mechanism of their selection process to form a raga which gives a unique character to the Indian classical music. The sacrifice that has been done regarding the harmonic structure has, no-doubt, been compensated by the availability of increased flexibility on the use of possible intervals to form melodic structures.

The utility of the effort made in this article is related to the recent advances in music industry. With the advent of digital and artificial methods to produce music, a number of changes have been observed regarding the creation and production of music. Digital adaptation of the *equal temperament* western scale has become ubiquitous, whereas the lack of systematic approach regarding the classical Indian music has prevented similar progress in terms of developing corresponding digital software and electronic equipment. The analysis, presented in this article, is an attempt to overcome this gap. More studies in this direction might aid the development of software and equipment suitable for just intonation scale operable on the continuous frequency range.

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