KNOWLEDGE-BASED RECOMMENDER SYSTEM USING FIRST ORDER LOGIC FOR INDIAN CLASSICAL MUSIC

K. R. Sekar, R. Ghurucharan, S. Depak and K. S. Ravichandran
School of Computing, SASTRA University, Tamil Nadu, India
E-Mail: sekar_kr@cse.sastra.edu

ABSTRACT

A recommender system is a type of system which performs filtering of information and produces useful inferences. In Indian classical music, a raga is a series of swaras (musical notes) in a particular order. Many musicians of Indian classical music follow the practice of transitioning from one raga to another while singing. The source raga and the destination ragas resulting from the transition have relationships with each other. In this research article, Carnatic music which is a form of Indian classical music, is taken as an application and a recommender system is proposed using methodologies related to Artificial Intelligence and other domains, like First Order Logic (FOL), gauging using distance measures and chi-square distribution in order to determine the destination ragas and their relationships with the source raga. Among the ragas which can be reached from a particular raga by raga-to-raga transition, the best-fit destination raga(s) are found out using distance measures. As an analysis of the gap between the source and destination ragas, one-way chi-square distribution is deployed. The hypothesis is tested for accuracy using confusion matrix. The application of this recommender system is to provide a list of all possible destination ragas reachable from an input source raga, thereby proving to be of great use to musicians, Music Information Retrieval (MIR) systems, automatic music creation software etc.

Keywords: recommender system, artificial intelligence, first order logic, gauging, Chi-square distribution, carnatic music.

1. INTRODUCTION

Recommender systems are very popular nowadays in diverse areas, catering to various useful needs. In this paper, a recommender system based on Knowledge-Based Inference (KBI) is proposed using various computational techniques like First Order Logic (FOL), gauging and chi-square distribution for Carnatic music, an Indian classical music form. The purpose of the recommender system is to find out the ragas that can be reached from a particular source raga using raga-to-raga transition which is famously called 'GrahaBhedam'. The utility of this recommender system is that it can determine the various destination ragas for a given input raga. In order to understand this system, it is important to understand the basic structure and concepts of Carnatic music which are discussed as follows.

Carnatic music is one of the finest and authentic forms of music that evolved from South India, that is, Tamil Nadu, Andhra Pradesh, Karnataka and Kerala. It is also considered as one of the contemporary forms of music since it is very much in practice even at present and it is being experimented every now and then by many musicians across the globe. There are various articles related to Carnatic music which examine its aspects greatly. In one such article by Krishna, T. M., & Ishwar, V., 2012, ragas, raga recognition, tonic, svara and gamaka are described. In the work by Bharucha, J. J., & Olney, K. L., 1989, a class of computational models called neural net is explained. The other prominent form of Indian music is the Hindustani music which is however, not explored in the present article. In the work by Vidwans, A., & Rao, P., 2012, some differences between Carnatic and Hindustani music are discussed.

Carnatic music consists of important elements that make it unique. Such elements are recognized and retrieved using some suggested methods by research articles. An example is the article by Nagavi, T. C., & Bhajantri, N. U., 2011 where an exhibition of an outline of past works on automatic Indian music information recognition, classification and retrieval is done.

The fundamental element of Carnatic music is the tonic note, 'Sruthi'. It is the musical pitch, forming the base scale, based on which the artist performs a song by maintaining this scale throughout the performance. Sruthi identification has been accomplished using De Cheveign´e& Kawahara's YIN algorithm and Interval Histogram Computation (Serra, J., Koduri, G. K., Miron, M., & Serra, X., 2011), autocorrelation based method, average magnitude difference function (AMDF) based method etc. (Gulati, S., Bellur, A., Salamon, J., Ishwar, V., Murthy, H. A., & Serra, X., 2014). In the work by Sinith, M. S., & Rajeev, K., 2007, "fundamental frequency tracking" algorithm, HMM and Dynamic Time Warping (DTW) are used to identify separate musical motifs in monophonic pieces.

The melodic modes 'ragas' which consist of patterns of notes called 'swaras' are inevitable elements of Carnatic music. Ragas define the tune of a song by making use of entire range of the octave 'Arohana' and 'Avarohana'. Many methodologies related to raga recognition exist like autocorrelation method (Karunakar, K., Suresh, G. V., Kumar, B. A., & Immanuel, T., 2012), Earth Movers distance (Rao, B. T., Mandhala, V. N., Bhattacharyya, D., & Kim, T. H., 2015; Rao, B. T., Chinnam, S., Kanth, P. L., &Gargi, M., 2012), HMM (Rajkumar, P. V., Saishankar, K. P., & John, M., 2011), spectral energy and component based segmentation of vocal signal with Harmonic Product Spectrum based algorithm (Sridhar, R., &Geetha, T. V., 2009), pitch class distribution, pitch class dyad distribution (PCDD) etc.

(Katte, T., 2013). Raga depiction is discussed using XML, Document Object Model (DOM) parsing and raaga (raga) reproduction algorithms in the work by Padyana, M., & Thomas, B. A., 2015.

The next important attribute, 'Tala' or rhythm of Carnatic Music, often referred to as the 'beat' helps an artist to maintain the tempo of the song. Several articles have examined the attributes of tala using techniques like pattern recognition and feature representation using inheritance and polymorphism (De, D., & Roy, S., 2012). The swaras are generalized as Sa, Ri, Ga, Ma, Pa, Dha, Ni, Sa usually represented as S, R, G, M, P, D, N, S where the first 'S' is sung in the low register and the last 'S' is sung in the high register. The two scales that contains the swaras are termed as 'Arohana' and 'Avarohana'. In Arohana, the ascending scale, the pitch increases as we go from first 'S' to last 'S' and it is vice versa for Avarohana, the descending scale. There are several methods to identify swaras. Some methods include fitness function based segmentation, granular segmentation and harmonic product spectrum algorithm (Sridhar, R., &Geetha, T. V., 2006), filter bank theory and SSM wavelets-based algorithms (Sinith, M. S., Tripathi, S., & Murthy, K. V. V., 2015). To generate swaras for a particular raga, some methodologies exist like First Order and Hidden Markov Models (Varadharajan, J., Sridharan, G., Natarajan, V., & Sridhar, R., 2014). Methods related to tone generation also exist and one such methodology is presented by Kumbhar, H., Limkar, S., & Kulkarni, R., 2015 using machine learning algorithm and Narmour structure analysis. Intonation is a raga feature and it is very essential to a singer's expression. In the paper by Koduri, G. K., SerràJulià, J., & Serra, X., 2012, an intonation illustration technique based on parameterization of histogram peak is presented.

The swaras 'R', 'G', 'D' and 'N' have three variations in them based on low, medium and high octaves which are 'R1', 'R2', 'R3' for R, 'G1', 'G2', 'G3' for G, 'D1', 'D2', 'D3' for D and 'N1', 'N2', 'N3' for N respectively. Similarly, the swara M has two variations which are 'M1' and 'M2' respectively whereas swaras 'S' and 'P' have no such variations. In a concert, the vocalist is often found to sing a sample of a particular raga before singing the song based on that raga. This is called alapana which is sung as a prelude to a song to show a trace of a raga. There are methods for identification and analysis of the motifs or patterns of swaras in an alapana like modified rough longest common subsequence algorithm, width-across-query and width-across-reference (Dutta, S., & Murthy, H., 2014).

A professional vocalist is witnessed to make transition from one raga to another by shifting the sruthi to any other swara in the same raga, which in turn makes him/her reach another raga. Likewise, there is a possibility of a raga belonging to one particular family, giving rise to one raga or many ragas belonging to different families. This practice of transitioning from raga to raga by shifting the tonic note is popularly referred to as 'GrahaBhedam' or 'SruthiBhedam' in Carnatic Music. We will refer to this practice in general terms as 'raga-to-raga transition' in the following sections for the readers to easily understand this concept. To comprehend this traditional concept of raga-to-raga transition, the two major categorizations of ragas must be known. They are Melakarta, the parent ragas and Janya, the children of those parent ragas. This classification of ragas has been implemented in many research papers. Some techniques are audio mining using data sampling, structural segmentation, feature extraction and clustering with NN classifier (Kirthika, P., &Chattamvelli, R., 2012).

The rules of Melakarta ragas must be known for this raga-to-raga transition, so they are given hereunder:

a) A Melakarta raga must have all 7 swaras S, R, G, M, P, D and N. Hence it is called a Sampurna (complete) raga. R denotes R1, R2 or R3; G denotes G1, G2 or G3; M denotes M1 or M2; D denotes D1, D2 or D3 and N denote N1, N2 or N3. The last swara, 'S' (higher octave) is always present in both the Arohana and Avarohana.
b) The notes should be strictly ascending and descending in Arohana and Avarohana respectively without leaps or windings.
c) The presence of more than one swara in the same category is not allowed. For example, both N1 and N3 should not be present in a Melakarta raga; only either of them is allowed.
d) The swaras in the Arohana and Avarohana of the raga are exact mirror-images of each other. They are laterally inverted; the swaras in the left appear in the right and vice-versa.

As every Melakarta raga is distinct from each other, each of them gives rise to child ragas, popularly called Janya ragas. Hence, Melakarta ragas are called parent (or) Janaka ragas. A Janya raga has a subset of swaras of its parent Melakarta raga. For example, Keeravani is a Melakarta raga and raga Jayashree is a Janya of it. In general, ragas can have their arohanas and avarohanas as exact mirror images of one another as we saw in the case of Melakarta ragas, which is considered as the symmetric nature; or else the Arohana and Avarohana can be different from each other, that is, the ragas are asymmetric in nature. A Janya raga can be symmetric or asymmetric in nature. In asymmetric ragas, there are two types. The first type is the asymmetric Janya ragas that resemble their parents in either Arohana or Avarohana. The second type consists of those that do not resemble their parents in Arohana or Avarohana. Thus, all these characteristics of Carnatic Music are to be known to realize the raga-to-raga transition concept.

The sections below are as follows. In Section 2, Related Works, some works related to Carnatic music are analysed. In Section 3, Proposed Methodology, divisions 3.1, 3.2, 3.3 and 3.4 deal with Bit Pattern and Bit Shifting, First Order Logic, Gauging using Distance Measures and Gap Analysis Model respectively. In Section 4, Performance Evaluation was done for the works related to Carnatic music and Section 5 contains the Confusion Matrix to calculate accuracy. These are followed by

Section 6, Empirical Validation, Section 7, Results and Discussion and Section 8, Conclusion.

2. RELATED WORKS

A lot of work is going on Carnatic music. Many articles pertaining to it have appeared and many more will keep appearing in the future also. Hence, in this section, a summary of some of the works is discussed for an understanding of what research is going on and also to derive useful information from the papers.

In the work by Chakraborty, S., & De, D., 2012, the tonic note was identified with an accuracy of 94% and the complexity in the objective analysis of the categorization problem of Carnatic music is expected to be reduced. An approach for raga identification is discussed in the paper by Daniel, H., &Revathi, A., 2015 in which identifying ragas and classifying them by group classification mechanisms achieved better results than MFCC method with 100% group classification accuracy. Another paper for raga identification is by Kumar, V., Pandya, H., &Jawahar, C. V., 2014 which achieves performance enhancement through combination pitch-class profiles and n-gram histogram with an accuracy of 83.39%. In the paper by Ranjani, H. G., Arthi, S., &Sreenivas, T. V., 2011 which analyses Carnatic music, elements like Shadja, raga and swara in an alapana are analysed with 88.8% Shadja identification, 91.5% swara identification and 62.13% in raga accuracies and the model is expected to lead to development of a similar model for janya ragas also. For polyphonic audio recordings, in the work by Koduri, G. K., Gulati, S., & Rao, P., 2011, 76.5% accuracy is achieved in identifying ragas. Pitch extraction is also accomplished.

Raga mining is accomplished in the work by Shetty, S., &Achary, K. K., 2009 in which the results are obtained successfully for monophonic songs and even polyphonic songs, with some misgivings in obtaining frequency. The system is expected to be enhanced in future by giving out notes and rhythm information. In the work by Priya, K., Ramani, R. G., & Jacob, S. G., 2012, the raga is recognized using arohana and avarohana scale. The Melakarta raga set was classified with 100% accuracy and the Janya raga set was classified with 90% accuracy. For Music Information Retrieval (MIR) systems, Sridhar, R., Amudha, A., &Karthiga, S., 2010 perform a comparison of Modified Dual Ternary Indexing and Multi-Key hashing algorithms with 65-70% precision, which is based on time and space complexities, precision and recall measures. The system is expected to be enhanced in future for identifying pattern sequence. In the work by Koduri, G. K., Miron, M., SerràJulià, J., & Serra, X., 2011, 94% accuracy is obtained in raga recognition by posterior rule with a multi-variate likelihood model. The system is expected to be enhanced in future by dealing with other properties of raga like gamaka. Dighe, P., Karnick, H., & Raj, B., 2013 achieve 94.28% accuracy in the scale independent raga identification method. Classifying genres and rhythms using Chroma and swara features is expected in future. In the work by Shetty, S., Achary, K. K., &Hegde, S., 2012b, 21 ragas of monophonic songs are identified by HMM and it is expected to be useful for MIR systems. In group identification, an accuracy of 85% and 65% accuracy in raga recognition are obtained.

In a paper by Suma, S. M., &Koolagudi, S. G., 2015, which is based on raga classification, ragas in 162 songs from 12 ragas are classified using Artificial Neural Network (ANN) with an accuracy of 89.5%. In the work by Shetty, S., Achary, K. K., &Hegde, S., 2012a, 21 ragas in monophonic songs are grouped using HMM and jump sequence and 70.69% accuracy is obtained; it is expected to be helpful for musicians and MIR systems. With accuracies of 89.98% in differentiating ragas and 89.67% in differentiating talas, rhythm and timbre related characteristics are examined in the paper by Heshi, R., Suma, S. M., Koolagudi, S. G., Bhandari, S., & Rao, K. S., 2015 to recognize raga and tala in music clips using T- test and GMMs. In the work by Bellur, A., & Murthy, H., 2013, September, the tonic pitch is recognized using pitch histograms and group delay function and it is expected to be useful for data-driven melodic examination. Accuracies of 84.01% using histogram and 90.70% using Group Delay (GD) histogram are achieved. Notes in ragas are recognized in the work by Prashanth, T. R., &Venugopalan, R., 2011 using T- test on a dataset of alapanas of 12 ragas with 90% accuracy. It is expected to be a base for raga recognition. In the work by Sheba, P., Maria, L. L., &Revathy, A., 2014, comparison of the raga recognition system using clustering algorithm with Mel Frequency Cepstral Coefficients (MFCC) and that with both MFCC and pitch characteristics is performed on 10 ragas. The methods are expected to be useful for MIR of Carnatic or film songs. The accuracies obtained are 55.10% and 65.22% for the 2 datasets using only MFCC characterisitics and 59.4% and 68.6% for the 2 datasets using MFCC and pitch frequencies.

Achievement in MIR is accomplished by Chithra, S., Sinith, M. S., & Gayathri, A., 2015 for polyphonic music with 100 songs in 4 languages using HMM. The accuracy is greater than 90% in all the 5 steps provided. In the paper by Salamon, J., Gulati, S., & Serra, X., 2012, the category of the pitch and the exact octave using multipitch examination on 364 musical pieces are determined and it is expected to be useful for automatic Indian music examination like identification of raga, inflection and melodic examination. An overall accuracy of 93% and 90% accuracy for Carnatic music are achieved. In the identification of patterns helping in a raga's recognition for a set of 5 ragas in the paper by Bellur, A., Ishwar, V., & Murthy, H. A., 2012, 80% of the patterns belong to a particular raga. In the work by Bellur, A., & Murthy, H. A., 2013, February, accuracy close to 100% is achieved in the tonic based on cepstrum and Non- Negative Matrix Factorization (NMF) is achieved. The tonic determination by Gulati, S., Salamon, J., & Serra, X., 2012 is achieved in 2 stages- multi-pitch inspection and evaluation of tonic octave by an iterative system. The accuracies are 92.96% without normalization and 76.67% with normalization for recognition of pitch group, and 96.62% for recognition of tonic octave.

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3. PROPOSED METHODOLOGY

The methodology applied to realize the ragas that can be reached from a particular source raga by shifting the sruthi (base note) to some other swara in the source raga is First Order Logic (FOL). The considered Melakarta ragas are Dheerashankarabharanam, Shanmukhapriya, Vachaspati, Keeravani, Harikambhoji and Chitrambari and the considered Janya ragas are Mohanam, Poorvavarali, Jayashree, Abheri, Devagandhari and Saramati out of which Mohanam is a symmetric Janya raga and the other five considered Janya ragas are asymmetric. To determine the destination ragas that can be reached from a particular source raga, the Arohana and Avarohana of each raga must be known. The Arohana and Avarohana are represented as a bit pattern consisting of 12 bits each representing a pitch interval, provided that the raga irrespective of being Melakarta or Janya has its Arohana and Avarohana as mirror images of one another, that is, the raga is symmetric in nature. Many papers regarding the twelve musical intervals are present and in the paper by Krishnaswamy, A., 2004c, the qualities of the 12 inflected distinct intervals are presented. Inflections are an important aspect in music associated with the musical intervals. Some discussions regarding them are available in many papers like the one by Krishnaswamy, A., 2004b where inflexions, and concerns related to computerized examination and production of Indian music are discussed and, another paper by Krishnaswamy, A., 2004a where pitch inflexions, sruthi etc. are analysed. In the paper by Krishnaswamy, A., 2003, some pitch inflexions are examined and STFT-based pitch tracking methodology is used to generate graphs of pitch tracks. The various stages in the process of raga-to-raga transition are depicted clearly in Figure-1.

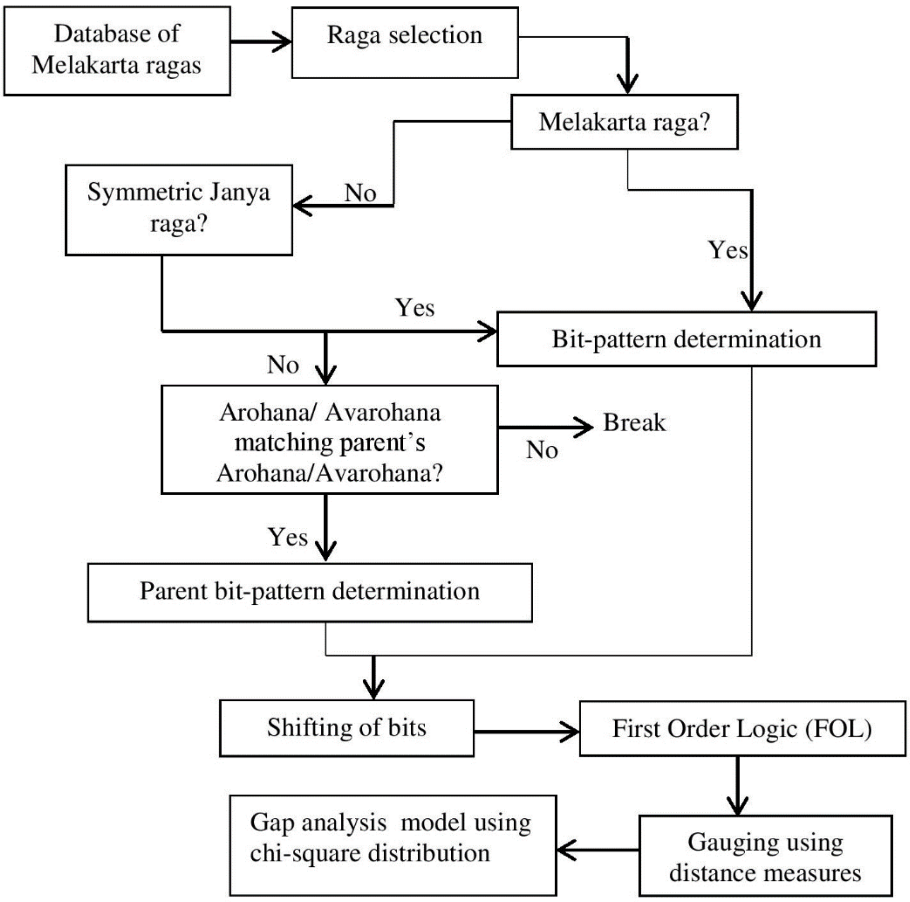

Figure-1. Raga-to-raga transition architecture.

3.1 Bit Patternand bit shifting

If a Janya raga is asymmetric and resembles its parent in either Arohana or Avarohana, i.e. in either the ascending or the descending scale, then the raga is taken in its parent's scale. The Janya raga is found to give the same result as its parent and also this holds for all the Janya ragas of each raga reached by the parent by raga transition. If this condition is satisfied, then raga-to-raga transition can be obtained by representing:

a) The Arohana of a raga in the form of a bit pattern, if it is a Melakarta raga or a symmetric Janya raga.
b) The Arohana/Avarohana of a raga in the form of a bit pattern, whichever matches its parent raga's Arohana, if it is an asymmetric Janya raga.

If an asymmetric Janya raga does not resemble its parent's Arohana or Avarohana, then the bit pattern cannot be determined for such ragas, so the raga transition is not

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possible using shifting of bits method. The reason why the Arohana of a raga is represented in the form of a bit pattern in case of a Melakarta raga and a symmetric Janya raga, and why the Arohana and Avarohana of a Janya raga are compared with its parent's Arohana, and not the parent's Avarohana, is that the bits in the bit pattern, when taken from left to right, correspond to swaras in the increasing order of their frequencies.

The way in which the bit pattern is represented is explained by the following requirements of a Melakarta raga, as Melakarta ragas being the parents form the base for the other ragas. In a Melakarta raga, there are certain rules that permit only some combinations for the swaras 'R' and 'G' and 'D' and 'N'. They are as follows:

a) If R1 is present in a raga, G1, G2 or G3 can be present. If R2 is present in a raga, either G2 or G3 can be present. If R3 is present in a raga then only G3 can be present. This can be represented as:

a. R1→G1, G2, G3R2→ G2, G3R3→G3
b. Thus, there are six combinations in total.

b) The above rule can be extended to 'D' and 'N'. Hence:

c. D1→N1, N2, N3D2→N2, N3D3→N3
d. Thus, there are six combinations in total.

The bit pattern is thus designed as a 12-bit binary number. According to the Melakarta raga scheme, based on the above two rules, in the bit pattern:
a) The swaras R2 and G1 take the same position.
b) The swaras R3 and G2 take the same position.
c) The swaras D2 and N1 take the same position.
d) The swaras D3 and N2 take the same position.

Based on the rule of combinations in a Melakarta raga, it is useless allotting a separate digit for each swara, as some might not be present in some ragas like R3. So instead of allotting a separate digit for every swara and going for a 16-bit number, twelve bits are only used for better efficiency in computation. Hence, in the bit pattern, only one digit has been allotted for R2 and G1, one digit for R3 and G2, one digit for D2 and N1 and one digit for D3 and N2. The bit pattern is represented in Figure-2.

S	R1	R2|G1	R3|G2	G3	M1	M2	P	D1	D2|N1	D3|N2	N3
1	1/0	1/0	1/0	1/0	1/0	1/0	1/0	1/0	1/0	1/0	1/0

Figure-2. Bit pattern.

In the bit pattern, '1' represents that the corresponding swara is present and '0' represents that the corresponding swara is not present. Here, swara 'S' is always present in a raga and hence its value is 1. The value of swara 'P' is 1 for Melakarta raga since it is always present in them but it can be 0 or 1 in the case of Janya ragas as they may or may not have 'P'. Now that we have represented the Arohana or Avarohana of a raga in the form of bits, as we know that 'S' is the tonic note, we look for the next consecutive swara that has the same value of swara 'S', that is '1' and consider that swara as 'S' and shift the swaras before them to the end and thereby arrive at a different raga. This is the idea behind raga transition.

But in the process of shifting of bits for a Melakarta raga as the source, if a resulting bit pattern does not represent the Arohana of a raga confirming to the rules of a Melakarta raga, the result is an invalid Melakarta raga and so it is not considered as a result of raga-to-raga transition. For example, for the raga Kharaharapriya, swaras are: S R2 G2 M1 P D2 N2 S. The bit pattern is 101101010110. Shifting with respect to R2 is done in the manner as shown in Figure-3.

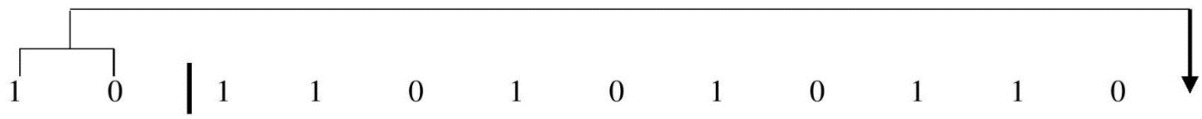

Figure-3. Shifting of bits in the bit pattern of Kharaharapriya with respect to swara R2.

The bit pattern thus obtained is 1 1 0 1 0 1 0 1 1 0 1 0 which matches the bit pattern of Hanumatodi that has its Arohana asS R1 G2 M1 P D1 N2 S. Likewise, the bits are shifted with respect to any bit that is '1' in the bit pattern and all possible destination ragas that can be travelled from a particular source raga are obtained. A special property is to be observed here which is as follows: From Dheerashankarabharanam, ragas 'Kharaharapriya', 'Hanumatodi', 'Mechakalyani', 'Harikambhoji' and 'Natabhairavi' are reached by shifting the base note to other distinct swaras. If any destination raga out of these destinations is chosen as the source, then the other destinations discussed above along with the old source raga are found to be reached from this new source raga. This is represented diagrammatically in Figures 4 to 9. As Figure-4 is true, then the figures Figure-5 to Figure-9 are also true. This property can be verified by applying the method of shifting of bits to each destination reached by the source raga considered. Using this special property, the concept of raga to raga transition is implemented using First Order Logic (FOL), where Backward Chaining is used.

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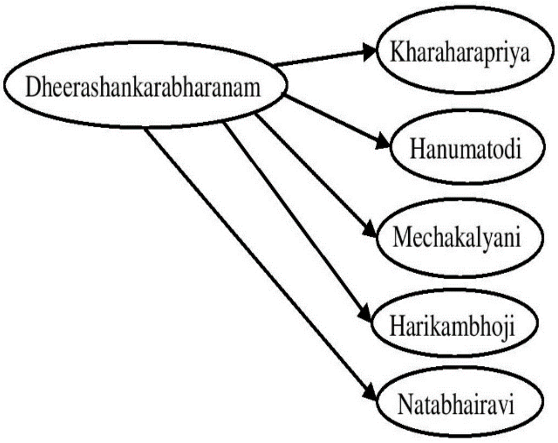

Figure-4. Ragas reachable from Dheerashankarabharanam.

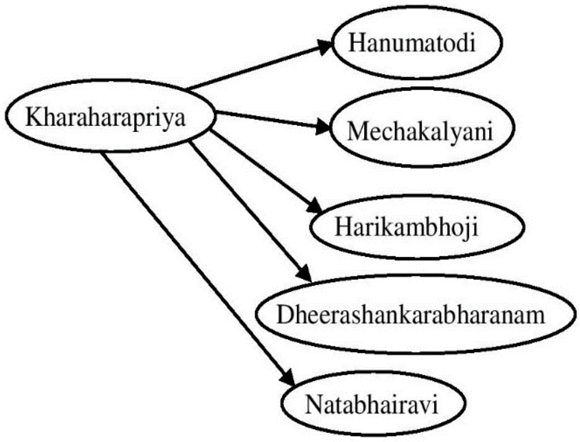

Figure-5. Ragas reachable from Kharaharapriya.

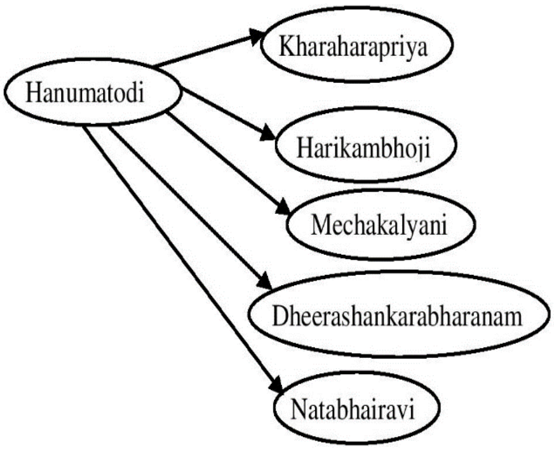

Figure-6. Ragas reachable from Hanumatodi.

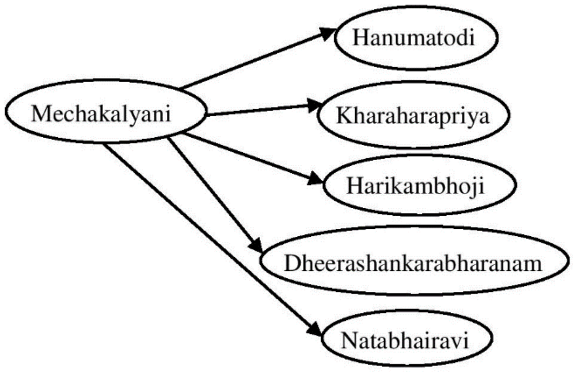

Figure-7. Ragas reachable fromMechakalyani.

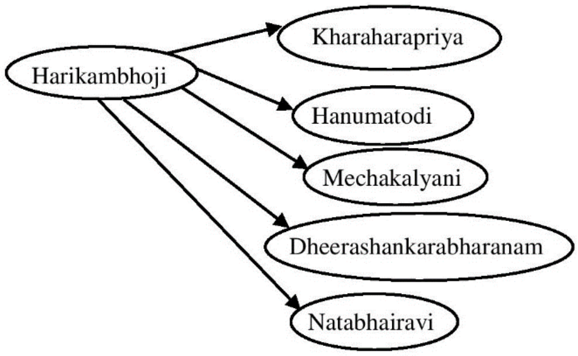

Figure-8. Ragas reachable from Harikambhoji.

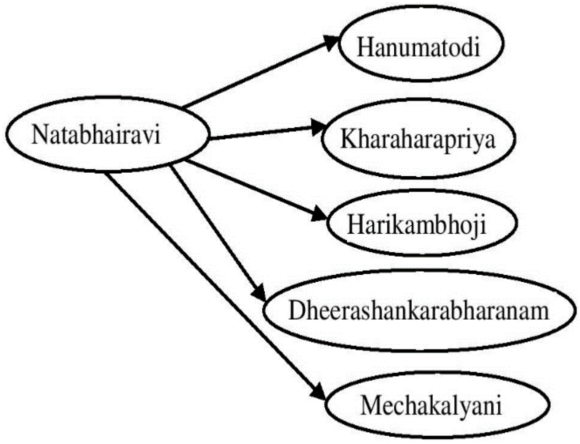

Figure-9. Ragas reachable fromNatabhairavi.

3.2 First order logic

First-order logic (FOL) is a system employed in mathematics and computer science. It is also called the first-order predicate calculus, predicate logic etc. First-order logic applies quantified variables on the objects that are non-logical. This differentiates it from propositional logic. Propositional logic does not employ quantifiers. A hypothesis about some subject matter is generally first-order logic along with a specified area of discussion on which the quantified variables span. Occasionally 'hypothesis' is interpreted in a more conventional sense, which is a set of predicates in first-order logic. FOL concept is used for this raga to raga travel concept due to the representation of entities as predicates. Each raga of the possible ragas reached by a particular source raga can be represented as a predicate.

For the solutions to be obtained, the inference method called Backward Chaining in FOL is used. Backward chaining is a method of inference that can be defined as working backward from a particular goal. It is employed in inference engines and several artificial intelligence domains. It begins using a set of goals and proceeds backwards from the resultant to the precursor to see if there is availability of data that will support any of these resultants. Hence, backward chaining is called 'goal-driven approach', where the inferences are obtained by the decisions made by a particular goal. If a particular goal has to be true, the sub-goals that result in this goal have to be true, and for those sub-goals to be true there must be several other sub-goals that make them true. In this manner, the proceedings are done by which sub-goals are derived from a goal and so on and, from these sub-goals, the new goals are obtained. These new goals from the solutions. The important part of this methodology is to choose the appropriate goal from which we derive some sub-goals and arrive at new goals which form the solutions.

To show that a source raga can reach some possible ragas, the goal was chosen as one of those ragas reached from the source raga and that raga is chosen as the new source and from it, the old source raga along with its possible destination ragas are obtained. This idea is also supported by the special property discussed in sub-division 3.1 in section 3. Using this technique, the transition from one raga to some possible ragas was determined for all the six Melakarta and six Janya ragas that were considered. The step-by-step procedure to carry out FOL for the Melakarta raga Dheerashankarabharanam is shown as an example. The special property is used here, as the source Mechakalyani is nothing but the destination of Dheerashankarabharanam itself. Mechakalyani is the goal, and from here, the proceedings are done by determining the sub-goals and thereby, the determination of relevant destination ragas of Dheerashankarabharanam is achieved. The resulting Melakarta ragas, their numbers, swaras and bit patterns obtained by shifting of bits of Mechakalyani are shown in Table 1. The raga name is Mechakalyani (Mck) and its Melakarta number is 65. Its swaras are S R2 G3 M2 P D2 N3 S and hence the bit pattern is 101010110101.

Table-1. Shifting of swaras for Mechakalyani.

S. No.	Swara chosen	Resulting Melakarta raga	Melakarta raga number	Swaras	Bit pattern
1.	D2	Kharaharapriya (Kp)	22	S R2 G2 M1 P D2 N2 S	101101010110
2.	N3	Hanumatodi (Hn)	08	S R1 G2 M1 P D1 N2 S	110101011010
3.	P	Dheerashankarabharanam (Dsb)	29	S R2 G3 M1 P D2 N3 S	101011010101
4.	R2	Harikambhoji (Hr)	28	S R2 G3 M1 P D2 N2 S	101011010110
5.	G3	Natabhairavi (Nb)	20	S R2 G2 M1 P D1 N2 S	101101011010

The goals are the following:

a) ∃ s, Shift(Mck,s)=>Raga(Hr) where s represents R2

b) ∃ s, Shift(Mck,s)=>Raga(Nb) where s represents G3

c) ∃ s, Shift(Mck,s)=>Raga(Dsb) where s represents P

d) ∃ s, Shift(Mck,s)=>Raga(Kp) where s represents D2

e) ∃ s, Shift(Mck,s)=>Raga(Hn) where s represents N3

Out of the goals mentioned above, a particular goal is chosen and then the proceeding is done from there. Here, the goal chosen is Shift(Mck,s)=>Raga(Hr)

∃s,(Shift(Mck,s)=>Raga(Nb)) ^ (Shift(Hr,s)=>Raga(Nb)) => (Shift(Mck,s)=>Raga(Hr)) (1)

Considering the individual predicates in the left-hand side of equation (1),

∃s,(Shift(Kp,s)=>Raga(Mck)) ^ (Shift(Kp,s)=>Raga(Nb)) => (Shift(Mck,s)=>Raga(Nb)) (2)

∃s,(Shift(Hn,s)=>Raga(Hr)) ^ (Shift(Hn,s)=>Raga(Nb)) => (Shift(Hr,s)=>Raga(Nb)) (3)

Considering the individual predicates in the left-hand side of equation (2),

∃s,(Shift(Dsb,s)=>Raga(Kp)) ^ (Shift(Dsb,s)=>Raga(Mck)) => (Shift(Kp,s)=>Raga(Mck)) (4)

∃s,(Shift(Dsb,s)=>Raga(Kp)) ^ (Shift(Dsb,s)=>Raga(Nb)) => (Shift(Kp,s)=>Raga(Nb)) (5)

Considering the individual predicates in the left-hand side of equation (3),

∃s,(Shift(Dsb,s)=>Raga(Hn)) ^ (Shift(Dsb,s)=>Raga(Hr)) => (Shift(Hn,s)=>Raga(Hr)) (6)

∃s,(Shift(Dsb,s)=>Raga(Hn)) ^ (Shift(Dsb,s)=>Raga(Nb)) => (Shift(Hn,s)=>Raga(Nb)) (7)

The left-hand sides of the equations (4), (5), (6) and (7) give the solutions and those of (1), (2) and (3) are the subgoals. The various predicates and their relationships are depicted in Figure-10.

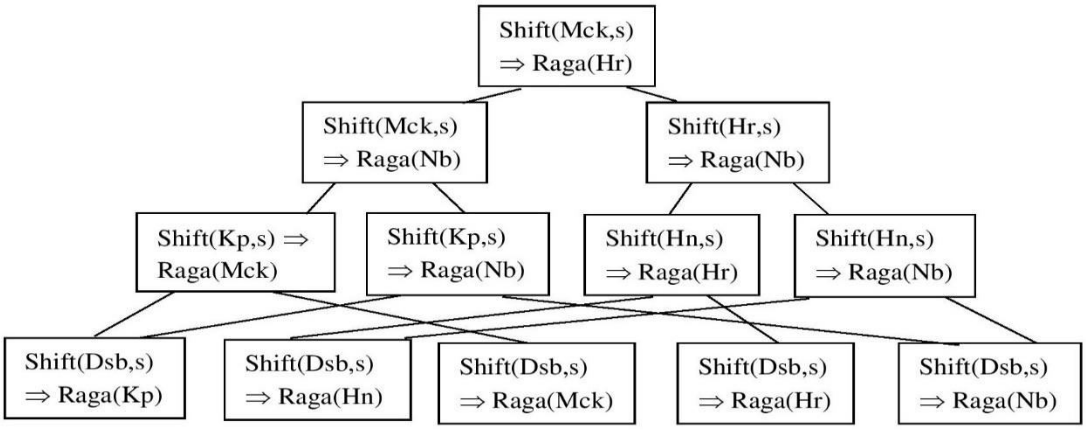

Figure-10. Backward chaining of Dheerashankarabharanam.

The solution is as follows:

The raga is Dheerashankarabharanam (Dsb) whose Melakarta number is 29. Its swaras are:S R2 G3 M1 P D2 N3 S. The bit pattern is 101011010101. The relevant-fit destination ragas of Dheerashankarabharanam obtained using First Order Logic are shown in Table-2.

Table-2. Relevant-fit destination ragas of Dheerashankarabharanam obtained using First Order Logic.

S. No.	Swara chosen	Resulting Melakarta raga	Resulting Melakarta raga's number	Swaras	Bit pattern
1.	R2	Kharaharapriya (Kp)	22	S R2 G2 M1 P D2 N2 S	101101010110
2.	G3	Hanumatodi (Hn)	08	S R1 G2 M1 P D1 N2 S	110101011010
3.	M1	Mechakalyani (Mck)	65	S R2 G3 M2 P D2 N3 S	101010110101
4.	P	Harikambhoji (Hr)	28	S R2 G3 M1 P D2 N2 S	101011010110
5.	D2	Natabhairavi (Nb)	20	S R2 G2 M1 P D1 N2 S	101101011010

3.3 Gauging using distance measures

The possible raga transitions from a particular raga have just been seen in sub-division 3.2 of section 3 using FOL. The relationships between the ragas themselves that can be reached from a particular source raga are also depicted. These observations are qualitative in nature. No observation has a numerical value to be analyzed. However, there is the need for determining the best-fit raga(s) among the ragas that can be obtained from a given source raga using raga transition. The best fit raga(s) are those that are closest to the source raga. Hence gauging (measurement) is performed using distance measures to find out the best-fit raga(s). The procedure for gauging using distance measures is as follows:

Step 1: To find the closeness of each of the destination ragas to the source raga, the bit pattern of the source raga which is taken as the reference is bitwise XOR-ed with the bit pattern of each of the destination ragas. The rules for a bitwise XOR operation are:

a) If the current bits in both the inputs are the same, the result is 0.
b) Else, the result is 1.

Step 2: The number of 1's in the result of the bitwise XOR operation are counted. This count yields the Hamming distance (or) difference between the bit patterns of the source raga and each of the destination ragas and is denoted as F(x), where 'x' is the bit pattern of a destination raga. Thus, we get Hamming distances from each of the destination ragas to the source raga.

Hence, the ragas having the least Hamming distance are the best-fit ones for the source raga. The least difference is recorded separately for future use. Here, the method employed is presented in a detailed manner for the Melakarta raga, Dheerashankarabharanam. The same steps are followed for all other 11 ragas considered. The swaras are S R2 G3 M1 P D2 N3 S and hence the bit pattern is 101011010101.

With respect to the source raga, Dheerashankarabharanam, the closeness of the ragas that can be obtained by bit shifting of the swaras is analysed. From Table-3, the differences between the bit patterns of the source raga (Dheerashankarabharanam) and each of the destination ragas are calculated and are shown in Figure-11.

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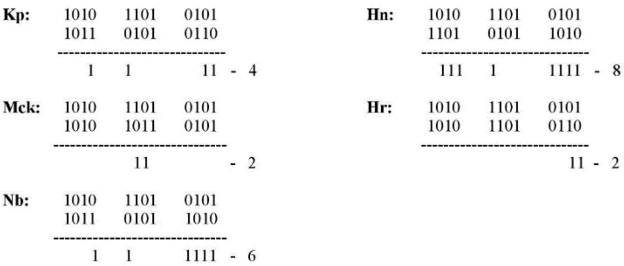

Figure-11. Differences between the bit patterns of Dheerashankarabharanam and each of the destination ragas.

The resulting Melakarta ragas, their bit patterns and distances from Dheerashankarabharanam in terms of bit pattern are shown in Table-3. The least difference (E) is 2 which are recorded for Mechakalyani and Harikambhoji. Following it, in Table-4, the solutions for First Order Logic and gauging using distance measures are summarised.

Table-3. Solution table of Dheerashankarabharanam.

S. No.	Resulting Melakarta raga	Bit pattern (x)	F(x)
1.	Kharaharapriya (Kp)	101101010110	4
2.	Hanumatodi (Hn)	110101011010	8
3.	Mechakalyani (Mck)	101010110101	2
4.	Harikambhoji (Hr)	101011010110	2
5.	Natabhairavi (Nb)	101101011010	6

Table-4. Solution table for First Order Logic (FOL) and gauging.

S. No.	Source raga	Swara	Relevant-fit destination ragas	Best-fit destination raga(s)
Melakarta ragas				
1	Dheerashankarabharanam (Dsb)	R2	Kharaharapriya(Kp)	Mechakalyani (Mck) Harikambhoji (Hr)
		G3	Hanumatodi(Hn)	
		M1	Mechakalyani(Mck)	
		P	Harikambhoji(Hr)	
		D2	Natabhairavi(Nb)	
2	Shanmukhapriya (Sp)	G2	Shoolini(Sl)	Chitrambari (Cb)
		P	Dhenuka(Dh)	
		D1	Chitrambari(Cb)	
3	Vachaspati (Vp)	R2	Charukesi(Ck)	Charukesi (Ck)
		P	Gowrimanohari(Gm)	
		D2	Natakapriya(Np)	
4	Keeravani (Ke)	M1	Hemavati(Hm)	Hemavati (Hm) Vakulabharanam (Va) Kosalam (Ko)
		P	Vakulabharanam(Va)	
		D1	Kosalam(Ko)	
5	Harikambhoji (Hr)	R2	Natabhairavi(Nb)	Kharaharapriya (Kp) Dheerashankarabharanam (Dsb)
		M1	Deerasankharabharanam(Dsb)	
		P	Kharaharapriya(Kp)	
		D2	Hanumatodi(Hn)	
		N2	Mechakalyani(Mck)	
6	Chitrambari (Cb)	G2	Shanmukhapriya(Sp)	Shanmukhapriya (Sp)
		P	Shoolini(Sl)	
		N3	Dhenuka(Dh)	
Janya ragas				
7	Mohanam (Mh)	R2	Madhyamavati (Mm)	ShuddhaSaveri (Ss)
		G3	Hindolam (Hl)	

		P	ShuddhaSaveri (Ss)	
		D2	ShuddhaDhanyasi (Sd)	
8	Poorvavarali (Pv)	R1	Asymmetric Janya ragas of parent raga Vishwambari (Vb) that resemble their parent in either Arohana or Avarohana	Asymmetric Janya ragas of respective parent ragas Vishwambari (Vb), Shamalangi (Sm) which resemble them in either Arohana or Avarohana
		G3	Asymmetric Janya ragas of parent raga Shamalangi (Sm) that resemble their parent in either Arohana or Avarohana	
9	Jayashree (Js)	M1	Asymmetric Janya ragas of parent raga Hemavati (Hm) that resemble their parent in either Arohana or Avarohana	Asymmetric Janya ragas of the respective parent ragas Hemavati (Hm), Vakulabharanam (Va), Kosalam (Ko) which resemble them in either Arohana or Avarohana
		P	Asymmetric Janya ragas of parent raga Vakulabharanam (Va) that resemble their parent in either Arohana or Avarohana	
		D1	Asymmetric Janya ragas of parent raga Kosalam (Ko) that resemble their parent in either Arohana or Avarohana	
10	Abheri (Ab)	M1	Asymmetric Janya ragas of parent raga Hariambhoji (Hr) that resemble their parent in either Arohana or Avarohana	Asymmetric Janya ragas of respective parent ragas Harikambhoji(Hr) and Natabhairavi(Nb) which resemble them in either Arohana or Avarohana
		P	Asymmetric Janya ragas of parent raga Natabhairavi (Nb) that resemble their parent in either Arohana or Avarohana	
		R2	Asymmetric Janya ragas of parent raga Hanumatodi (Hn) that resemble their parent in either Arohana or Avarohana	
		G2	Asymmetric Janya ragas of parent raga Mechakalyani (Mck) that resemble their parent in either Arohana or Avarohana	
		N2	Asymmetric Janya ragas of parent raga Dheerashankarabharanam (Dsb) that resemble their parent in either Arohana or Avarohana	
11	Devagandhari (Dg)	R2	Asymmetric Janya ragas of parent raga Kharaharapriya (Kp) that resemble their parent in either Arohana or Avarohana	Asymmetric Janya ragas of respective parent ragas Harikambhoji(Hr) and Mechakalyani(Mck) which resemble them in either Arohana or Avarohana
		G3	Asymmetric Janya ragas of parent raga Hanumatodi (Hn) that resemble their parent in either Arohana or Avarohana	
		M1	Asymmetric Janya ragas of parent raga Mechakalyani (Mck) that resemble their parent in either Arohana or Avarohana	
		P	Asymmetric Janya ragas of parent raga Harikambhoji (Hr) that resemble their parent in either Arohana or Avarohana	
		D2	Asymmetric Janya ragas of parent raga Natabhairavi (Nb) that resemble their parent in either Arohana or Avarohana	
12	Saramati (St)	G2	Asymmetric Janya ragas of parent raga Dheerashankarabharanam (Dsb) that resemble their parent in either Arohana or Avarohana	Asymmetric Janya ragas of respective parent ragas Kharaharapriya(Kp) and Hanumatodi (Hn) which resemble them in either Arohana or Avarohana
		M1	Asymmetric Janya ragas of parent raga Kharaharapriya (Kp) that resemble their parent in either Arohana or Avarohana	
		P	Asymmetric Janya ragas of parent raga Hanumatodi (Hn) that resemble their parent in either Arohana or Avarohana	
		D1	Asymmetric Janya ragas of parent raga Mechakalyani (Mck) that resemble their parent in either Arohana or Avarohana	
		N2	Asymmetric Janya ragas of parent raga Harikambhoji (Hr) that resemble their parent in either Arohana or Avarohana	

3.4 Gap analysis model

First Order Logic (FOL) was used to depict the transition from one raga to several other possible ragas and our goal was arrived at, which is a therefore a goal-driven approach. Next, the gauging method was used to determine the best-fit raga(s) of all the ragas that can be reached from a source raga. Any hypothesis should be validated so that it holds and its results also hold. A probability distribution is generally used to analyse the spread of the values computed in a population. A probability is allotted to every subset of the likely results of a statistical mechanism that can be measured. Techniques like normal distribution, exponential distribution, chi-square distribution etc. are examples of probability distributions.

As evident from the above paragraph, our results of First Order Logic (FOL) and gauging method are valid only if our hypothesis is true. Hence, as a gap analysis model, for the determination of whether the hypothesis is true, we determine the one way chi-square distribution for the set of ragas that can be reached from a particular source raga. The one way chi-square distribution is chosen because it is normally used to find out how good the fit of the observed distribution is, with respect to a theoretical distribution. The procedure is as follows:

Step 1: The results of the gauging process are carried further here to assess the validity of our hypothesis. A table is maintained in order to store some values which will be needed in validating our hypothesis. Let 'n' be the number of destination ragas. The differences obtained for each of the destination ragas from a particular raga are normalized and stored in the table as Observed difference, O_i ,i=1,2,…,n.

Step 2: The least difference value previously recorded as a finding in the Gauging method is also normalized and stored in the table as Expected difference, E.

Step 3: Using the results of steps 1 and 2, O_i - E values are found for each destination raga and stored for i=1, 2,…,n.

Step 4: Using the results of step 3, $(O_i - E)^2$ values are found for each destination raga and stored for i=1,2,…,n.

Step 5: Using the results of steps 2 and 4, $\frac{(Oi-E)2}{E}$ values are found for each destination raga and stored for i=1,2,…,n.

Step 6: Using the results of step 5, $\sum_{i=1}^{n}\left(\frac{(Oi-E)2}{E}\right)$value is found.

Step 7: Likewise, for each of the 'n' destination ragas reachable from a source raga, the values of $\sum_{i=1}^{n}\left(\frac{(Oi-E)2}{E}\right)$ are compared with the standard chi-square distribution table in the column labelled '0.05'in order to check whether the error in computation is within 5%. The degree of freedom in each case is n-1. The results are shown in Table-5 for Dheerashankarabharanam as the source raga.

Table-5. Gap analysis table for Dheerashankarabharanam.

Source raga	Rest of the ragas	Observed difference O_i	Expected difference E	$O_i - E$	$(O_i - E)^2$	$\frac{(Oi - E)2}{E}$
Dsb	Kp	0.18	0.2	-0.02	0.0004	0.002
	Hn	0.36	0.2	-0.16	0.0256	0.128
	Mck	0.09	0.2	0.11	0.0121	0.0605
	Hr	0.09	0.2	0.11	0.0121	0.0605
	Nb	0.27	0.2	0.07	0.0049	0.0245

The sum of the values of the last column in Table-5 is 0.2755. In this case, n = 5, so n-1 = 4. As 0.2755 < 9.49, where 9.49 is the value under the column of chi-square distribution table labelled '0.05'for a degree of freedom of 4, our hypothesis is correct. The process described above yields $\sum_{i=1}^{n}\left(\frac{(Oi-E)2}{E}\right)$ values within 5% error for all 12 source ragas considered. Hence,it is proved that our hypothesis of the raga-to-raga transition is correct. In this manner, the calculations are done for all the 12 source ragas and the solutions are listed in Table-6.

Table-6. Solution table for one way chi-square distribution.

S. No.	Source raga	$\sum_{i=1}^{n}\left(\frac{(Oi-E)2}{E}\right)$	S. No.	Source raga	$\sum_{i=1}^{n}\left(\frac{(Oi-E)2}{E}\right)$
MELAKARTA RAGAS			JANYA RAGAS		
1	Dheerashankarabharanam (Dsb)	0.2755	7.	Mohanam (Mh)	0.3404
2	Shanmukhapriya (Sp)	0.0711	8.	Poorvavarali (Pv)	0
3	Vachaspati (Vp)	0.0310	9.	Jayashree (Js)	0
4	Keeravani (Ke)	0	10.	Abheri (Ab)	0.2755
5	Harikambhoji (Hr)	0.1710	11.	Devagandhari (Dg)	0.2755
6	Chitrambari (Cb)	0.0711	12.	Saramati (St)	0.2755

4. PERFORMANCE EVALUATION

Various papers related to Carnatic music exist and they provide a lot of information. It is very useful to examine them to derive great knowledge out of the papers. Hence, some of the papers have been analysed and their category, methodologies and Quality of Service are presented in the following table, Table-7.

Table-7. Performance evaluation.

S. No.	Category	Methodologies	Quality of Service (QoS)	Percentage obtained
1	Carnatic Music Introduction and Characteristics	Histograms, pitch contours, multivariate likelihood model	Accuracy and Demonstrability	Accuracy: 94%
2	Music Information Retrieval	HMM, modified Schroeders histogram, Baum-Welch algorithm, dual ternary indexing algorithm and multi key hashing indexing algorithm, cross-validation and confidence intervals	Accuracy, Precision and Reliability	Accuracy: >90% Precision: 65% to 70%
3	Tonic Recognition	Inheritance, De Cheveign´e& Kawahara's YIN algorithm, pitch histograms and group delay functions, autocorrelation, Average magnitude difference function (AMDF), predominant pitch estimation, pitch histograms, semi-continuous GMM fitting, cepstrum and Non-Negative Matrix Factorization (NMF)-based methods, classification-based methodology	Accuracy, Simplicity, Efficiency, Demonstrability and Determinability	Precision ~100% Determinability:90.70 % Demonstability: 90% Efficiency: 93% Accuracy: 95.3%
4	Raga identification	Autocorrelation method, back-propagation neural networks, K-Nearest Neighbours, chromagram-based algorithm, random forest classifier, HMM, k-means clustering technique, machine learning, Mel Frequency Cepstral Coefficient Extraction, Artificial Neural Nets, segmentation of vocal signal with harmonic product spectrum-based algorithm, Cosine distance, Specmurt analysis, pitch class distribution and pitch class dyad distribution	Accuracy, Simplicity, Efficiency, Effectiveness, Robustness and Determinability	Accuracy: 93.33% Determinability: 94.28% Efficiency: 83.2% Effectiveness: 70.69% Robustness: 80%
5	Rhythm analysis	Pattern Recognition and Feature representation using Inheritance and Polymorphism, T- test and Gaussian Mixture Models (GMMs).	Usability and Determinability	Determinability: 89.67%
6	Swara identification	A fitness function-based segmentation, granular segmentation, harmonic product spectrum algorithm, filter bank theory-based algorithm and SSM wavelets- based algorithm, C4.5 decision tree algorithm, random tree algorithm, rule induction algorithm, feature ranking, correlation-based feature selection and fast correlation-based filter, enhanced auto-correlation and T- test.	Effectiveness, Optimization and Accuracy	0.3061% of memory consumed in DSP chip Accuracy: 95%
7	Alapanas	Modified rough Longest Common Subsequence algorithm, Width-Across-Query and Width-Across-Reference and Semi-continuous Gaussian Mixture Model.	Accuracy	Accuracy:91.5%
8	Raga classification	Audio mining, structural segmentation, feature extraction and clustering with NN classifier, pitch-class profile distribution and n-gram histogram distribution, SVM framework, probability density function (pdf) of the pitch contour and Artificial Neural Network (ANN).	Efficiency, Enhancement, Effectiveness and Determinability	Enhancement and effectiveness: 83.39% Determinability:89.5 %

5. CONFUSION MATRIX

The detailed process of raga-to-raga transition has been discussed in the previous sections. Using methodologies like First Order Logic and gauging, the relevant-fit and best-fit destination ragas have been determined for all the 12 source ragas. In Table-8, the relevant-fit destination ragas, numbers of best-fit and least-fit destination ragas have been provided for all the source ragas. The ragas in the column 'Relevant-fit destination ragas' which are highlighted in red colour are the best-fit ragas that were obtained by gauging using distance measures.

Table-8. Impression of the confusion matrix.

Source raga	Relevant-fit destination ragas	Number of best-fit destination ragas	Number of least-fit destination ragas	Total number of relevant-fit destination ragas
Dheerashankarabharanam (Dsb)	Kharaharapriya (Kp) Hanumatodi (Hn) Mechakalyani (Mck) Harikambhoji (Hr) Natabhairavi (Nb)	2	3	5
Shanmukhapriya (Sp)	Shoolini (Sl) Dhenuka (Dh) Chitrambari (Cb)	1	2	3
Vachaspati (Vp)	Charukesi (Ck) Gourimanohari (Gm) Natakapriya (Np)	1	2	3
Keeravani (Ke)	Hemavati (Hm) Vakulabharanam (Va) Kosalam (Ko)	3	0	3
Harikambhoji (Hr)	Natabhairavi (Nb) Dheerashankarabharanam (Dsb) Kharaharapriya (Kp) Hanumatodi (Hn) Mechakalyani (Mck)	2	3	5
Chitrambari (Cb)	Shanmukhapriya (Sp) Shoolini (Sl) Dhenuka (Dh)	1	2	3
Mohanam (Mh)	Madhyamavati (Mm) Hindolam (Hl) ShuddhaSaveri (Ss) ShuddhaDhanyasi (Sd)	1	3	4
Poorvavarali (Pv)	Asymmetric Janya ragas of respective parent ragas Vishwambari (Vb), Shamalangi (Sm) which resemble them in either Arohana or Avarohana	2	0	2
Jayashree (Js)	Asymmetric Janya ragas of the respective parent ragas Hemavati (Hm), Vakulabharanam (Va), Kosalam (Ko) which resemble them in either Arohana or Avarohana	3	0	3
Abheri (Ab)	Asymmetric Janya ragas of respective parent ragas Harikambhoji(Hr), Natabhairavi(Nb), Mechakalyani(Mck), Dheerashankarabharanam (Dsb), Hanumatodi (Hn) which resemble them in either Arohana or Avarohana	2	3	5
Devagandhari (Dg)	Asymmetric Janya ragas of respective parent ragas Harikambhoji(Hr), Mechakalyani(Mck), Natabhairavi(Nb), Kharaharapriya(Kp), Hanumatodi (Hn) which resemble them in either Arohana or Avarohana	2	3	5
Saramati (St)	Asymmetric Janya ragas of respective parent ragas Kharaharapriya(Kp), Hanumatodi (Hn), Mechakalyani(Mck), Harikambhoji(Hr), Dheerashankarabharanam (Dsb) which resemble them in either Arohana or Avarohana	2	3	5
Total		22	24	46

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The accuracy calculationis as follows:
Total number of destination ragas obtained = 46
Total number of best-fit destination ragas = 22
Total number of least-fit destination ragas = 24

$$\text{Accuracy} = \frac{100 \times \text{Total number of best-fit ragas}}{\text{Total number of ragas obtained}}$$

$$= (100 \div 46) \times 22 = 47.8\%$$

Hence, it is observed that 47.8% of the 46 obtained ragas give 100% accuracy. This fact can also be stated that 22 best-fit ragas out of 46 obtained ragas give 100% accuracy whereas the remaining 24 least-fit ragas have achieved accuracy less than 100%. For a visual understanding of the raga-to-raga transitions for all the 12 source ragas considered, graphs showing the numbers of relevant-fit, best-fit and least-fit destination ragas are plotted. They are given in Figures 12 to 23.

There is a magnificent tool to determine the relationships between different families of ragas which is called 'Grahabhedam explorer' tool. This is the best known, recognized tool to determine all possible raga-to-raga transitions. Hence, this tool was utilized to verify our results. It was observed that our obtained results are in compliance with the results displayed by the tool. A sample screenshot of the tool is shown in Figure-24.

Figure-12. Plot forDheerashankarabharanam.

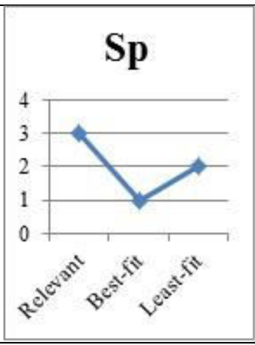

Figure-13. Plot for Shanmukhapriya.

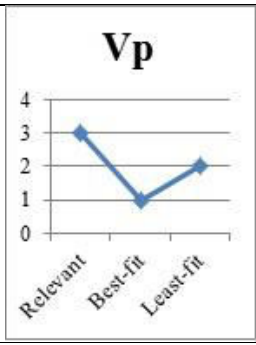

Figure-14. Plot for Vachaspati.

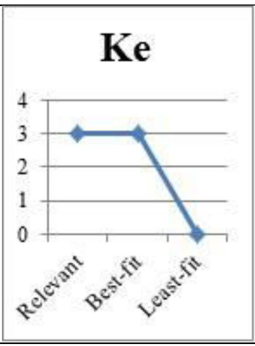

Figure-15. Plot for Keeravani.

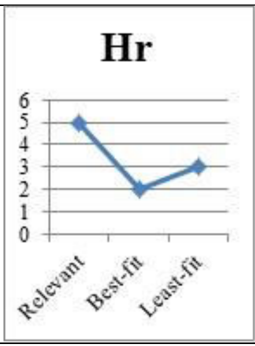

Figure-16. Plot for Harikambhoji.

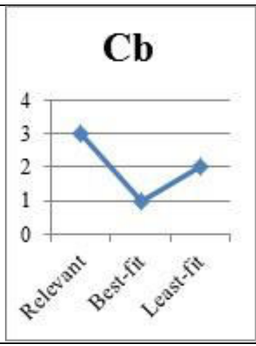

Figure-17. Plot for Chitrambari.

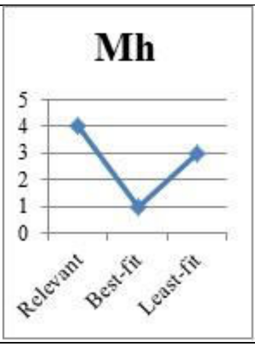

Figure-18. Plot for Mohanam.

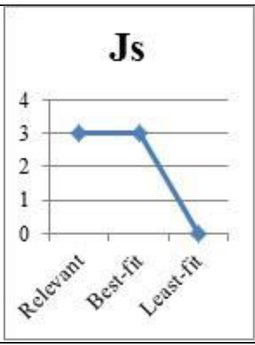

Figure-19. Plot for Jayashree.

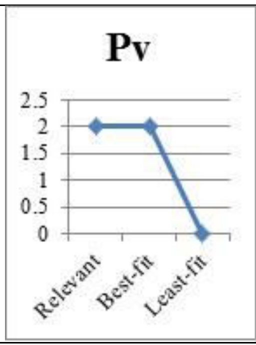

Figure-20. Plot for Poorvavarali.

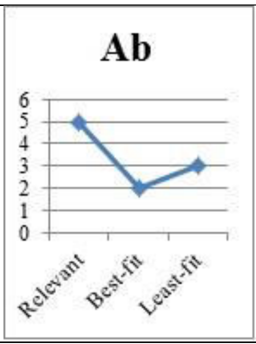

Figure-21. Plot for Abheri.

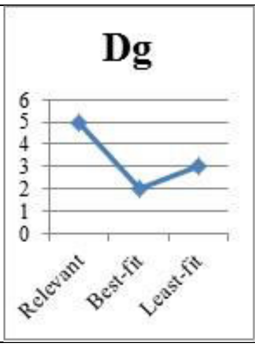

Figure-22. Plot forDevagandhari.

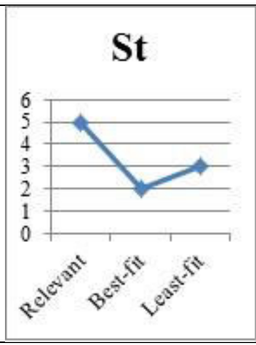

Figure-23. Plot for Saramati.

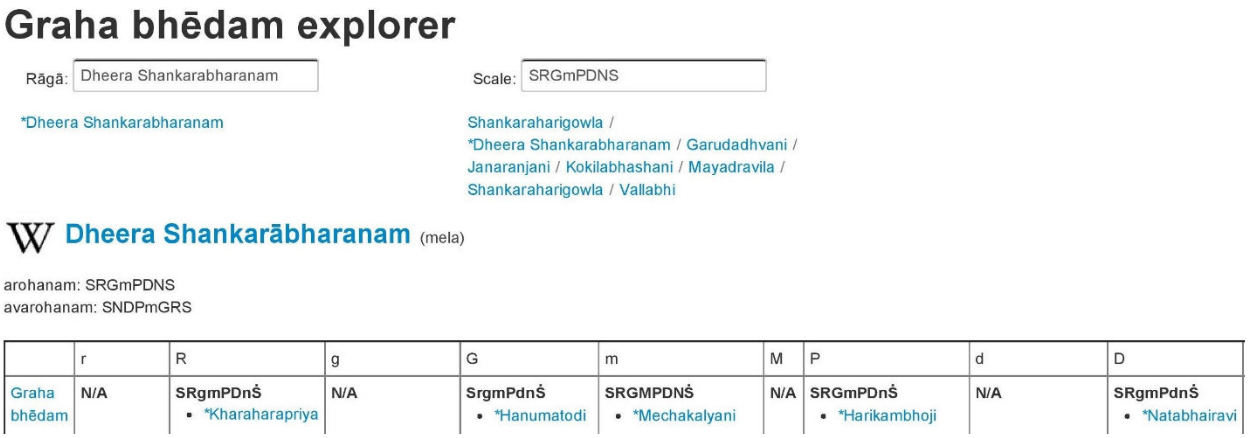

Figure-24. A sample screenshot of 'Grahabhedam explorer' tool.

6. EMPIRICAL VALIDATION (ONLINE VIDEOS AND REFERENCES ARE CITED BELOW)

Apart from the theoretical perspective of the concept of raga-to-raga transition, the insight of this concept from various musicians' perspective is also presented here. It is inferred from the online articles (Ashok, M. (2010, April 29). GNB- Much Ahead of His Time. Retrieved from http://www.carnaticcorner.com/articles/GNB.htm; Sriram, N. (2013, June 23). GNB1. Retrieved from https://prezi.com/atclx5asc6t0/gnb1/) that one of the greatest maestros of Carnatic Music, G.N. Balasubramaniam popularized this fascinating concept. His proficiency over this technique has inspired a lot of other musicians to experiment with several ragas and explore the way in which they were connected. Thus GrahaBhedam or raga-to-raga transition was mastered by several other stalwarts after his generation, like M. L. Vasanthakumari, who was a prime disciple of G.N. Balasubramaniam (Ramnarayan, V. (2012,July 15). GNB's Disciples. Retrieved from http://srutimag.blogspot.in/2012/07/gnbs-disciples.html) and Dr. M. Balamuralikrishna. It is to be noted that Dr. M. Balamuralikrishna popularized GrahaBhedam through his most famous composition "Jaya RagamalikaThillana" released in 1986. (Balamuralikrishna, M. (1986). Thillanas- M. Balamuralikrishna. Retrieved from https://itunes.apple.com/in/album/thillanas-m.-balamuralikrishna/id1003082907; Sara, R. (2013, June 13). Virtuosos dazzle. Retrieved from http://www.thehindu.com/features/friday-review/music/virtuosos-dazzle/article4810297.ece). In the present world, there have been several renowned musicians, lecturers and music enthusiasts who have been experimenting their renditions with this astounding raga-to-raga transition. Gayatri, of the most famous Carnatic music duo Ranjani-Gayatri had presented a lec-dem on GrahaBhedam at The Music Academy, Chennai on 16th December 2015 as a part of the Morning Acadmic Sessions. In this event, she had explored the interrelationships of most of the familiar Melakarta and Janya ragas and performed the raga-to-raga transitions for the same (Ramkumar, R. (2015, December 16). LEC DEM by Gayatri– A Few Perspectives OnGrahabhedam. Retrieved from https://ramsabode.wordpress.com/2015/12/16/ld_gayatri_grahabhedam_ma15/ ; Gayatri. (2015, December 25). RanjaniGayatriLecdem on GrahaBhedam. Retrieved from https://www.youtube.com/watch?v=g8w4Yx767mM).
Palakkad Sreeram, an acclaimed Carnatic music trainer has implemented GrahaBhedam in some of his online videos among which his transitions between the ragas Surutti and Thodi is well known (Palakkadsreeram, L. (2014, August 16). Surutti inside Thodi by PALAKKAD SREERAM. Retrieved from https://www.youtube.com/watch?v=f_69bmPTAjE).
Kavalam Sreekumar, a famous singer has shown transitions from Mohanam to Suddha Dhanyasi, Suddha Saveri and Madhyamavathi in his performance in a popular reality show (Kavalam, S. (2011, May 15).

HINDOLAM SRUTHI BHEDAM Retrieved from https://www.youtube.com/watch?v=ewdkkez43-Y).

Table-9. Empirical Validation done to substantiate the findings.

S.No.	Musicians' names	No. of recordings	No. of best-fit ragas transitioned according to our research work	% obtained
1	G. N. Balasubramaniam	6	6	100%
2	M. L. Vasanthakumari	7	6	86%
3	M. Balamuralikrishna	12	11	92%
4	Prince Rama Varma	10	9	90%
5	Ranjani-Gayathri	20	19	95%
6	Guitar Prasanna	15	14	93%
7	SriramParthasarathy	9	9	100%
8	PalakadSreeram	8	7	88%

SriramParthasarathy, a renowned Carnatic music and light music artist has also been actively engaging himself in incorporating this concept in his performances. One of his most popular online videos is the one where he has explored transitions between ragas like Bowli, Sivaranjani, Hamsanandhi, Gowrimanoharietc (Sriram, P. (2014, January 29). SriramParthasarathy-Exploring various musical genres. Retrieved from https://www.youtube.com/watch?v=X356Kl7t44M).
Renowned instrumentalists have also involved themselves with experimenting this concept on their renditions. A great example is Prince Rama Varma, a renowned Veena player who has shown his profess in this technique in various concerts. He presented a lecture demonstration on SruthiBhedam in 2008 and he showed how to transition between the ragas Sindhu Bhairavi and Behag in Veena. (ShruthiBhedam (Sindhubhairavi/Behag). (2008, August 24). Retrieved from https://www.youtube.com/watch?v=Nnq5tdukBeg).
Another example is the most famous Carnatic musician R. Prasanna who plays Carnatic music on electrical guitar. Prasanna amazed his audiences in a concert where he transitioned between the ragas Kharaharapriya and Dheerasankarabharanam (Shalini, L. (2007, January 19). Prasanna plays Karaharapriya raga. Retrieved from https://www.youtube.com/watch?v=Qy3cIgf2Vdc).
Instructors from several music schools are also inspired by this wonderful theory and they are training their students pertained to raga-to-raga transition. One such instructor is Ramaprasad KV from Mahati School of Music, California has been teaching this concept to his students for the past four years. He posted an online video of his class on GrahaBhedam (Ramaprasad, KV. (2012, July 23). GrahaBheda - A Beginner's Guide. Retrieved from https://www.youtube.com/watch?v=YrYOoTR9xes).

Right from the above fact, it is very obvious that the mathematical work in this research paper is literally matched with 86% to 100% towards the outcome of this paper.

7. RESULTS AND DISCUSSIONS

Any work requires an introduction to its subject because it is fundamental in understanding the concepts. Hence, in the Introduction section, Carnatic music and its basic elements like sruthi, raga, tala, tonic etc. and works related to these topics were explored. At first, the architecture diagram (Figure-1) was provided which summarizes the whole process of raga-to-raga transition. In the process of raga transition, 12 ragas- 6 Melakarta and 6 Janya from the database of ragas were selected. The chosen Melakarta ragas are Dheerashankarabharanam, Shanmukhapriya, Vachaspati, Keeravani, Harikambhoji and Chitrambari and the chosen Janya ragas are Mohanam, Poorvavarali, Jayashree, Abheri, Devagandhari and Saramati. Next, to explore raga-to-raga transition, the proceedings were done by considering one of the 12 ragas as the source at a time. The bit pattern for the source raga was determined. Then, shifting of bits was performed to arrive at the possible ragas that can be reached from the source raga and those reachable relevant fit ragas were verified using First Order Logic (FOL). Table-1 indicates the ragas obtained from Mechakalyani via shifting the bits and Table-2 indicates the ragas obtained from Dheerashankarabharanam via FOL. From these relevant fit ragas, to find out the best-fit raga(s), a gauging based on differences between each destination and the source was carried out and results obtained for Dheerashankarabharanam are shown in Table-3. Analyzing the solution table for FOL and gauging (Table-4), it is evident that one or more ragas among the destination ragas are the best-fit ragas for the source. If all the destination ragas are best-fit ones, it is inferred that for such source ragas, FOL itself gives the best-fit ragas. Finally, to take FOL and gauging one step forward and analyze the gaps between each destination raga and the source, one-way chi-square distribution method was used for all considered ragas (like Table-5 which is for Dheerashankarabharanam) to prove the correctness of our hypothesis. From its solution table (Table 6), it is observed that the ragas, which have the value '0' in the last column-ragas Keeravani, Poorvavarali and Jayashree, have 100% accuracy. This fact was already found out from Table 4.

Tremendous amount of work is going on Carnatic music, so as an inference from various articles in different categories of Carnatic music, Table 7 provides the Quality of Service (QoS) in each category along with the average percentages of the methodologies collected in that category. To determine the accuracy in terms of the best and least-fit destination ragas, an impression of the confusion matrix was formed in Table 8 which lists out the number of best and least-fit ragas for each source raga, where 47.8% of 46 obtained ragas give 100% accuracy. It is to be clearly noted that this is not the accuracy of the process itself, but it is a measure of how many destination ragas are close to the source raga. If the accuracy is 100%, it means that the destination ragas are closest (best-fit) to the source raga and if it is less than 100%, the ragas are least-fit for the source. In Table 9, the empirical validation of the concept with reference to the musicians' names and their recordings has been presented for substantiating our mathematical work and the outcome.

8. CONCLUSIONS

Research on music has many applications. In the way based on Knowledge-Based Inference (KBI) which means deriving some information from the available dataset, the proposed raga-to-raga transition method and its analysis will guide a Carnatic singer to show his extempore while performing in a concert. Not only for vocalists, this concept is also greatly useful for music enthusiasts who wish to learn and enjoy the aspects of Carnatic music. This concept will also lead the music composers to experiment with various ragas. This raga transition is also of great use in Music Information Retrieval (MIR) systems because raga transition determines the relationships among a set of ragas. The proposed method only has the limitation that it cannot handle a Janya raga if it is asymmetric and its Arohana/Avarohana does not match its parent's Arohana/Avarohana. It is because, as already mentioned, a bit pattern cannot be formulated for such a raga according to the method of formation of bit pattern given in the paper. Hence, in the future, this methodology has to be improved further so that the system can handle all types of ragas.

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