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A Comparative Study between Properties of Carnatic Raagas and Emotions of Devotional Songs Using Bidirectional Associative Memories (BAM)

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Abstract

Art is a means of expressing emotions to the fullest. One element that is common among all performing arts is their ability to express the emotions which make up different slices of life. Emotions characterize life as well as art. Music is one such language of emotions. In this paper, we propose an idea of how the properties of Carnatic raagas (Indian Classical Music) relate with the emotions while listening Tamil Christian devotional songs. This paper consists of four sections. Section 1 describes some basic ideas of Indian Classical Music and few previous works on it. The proposed method from the field of fuzzy logic is demonstrated in Section 2. Section 3 provides the description of the problem and hidden pattern. The conclusion of this paper is given in the final section

Key words *Carnatic music, Neuronal dynamical system, Bivalent additive BAM, Synaptic connection matrices.*

1. Introduction

In 2004, Shivani Yardi et. al analysis show strong correspondence between the pitch patterns of each raga and its emotion and traditional performance time with the use of the Harmonic Network [1]. Parag Chordia and Alex Rae results suggest that *raagas* do consistently elicit specific emotions that are linked to musical properties and the responses from people did not differ significantly for enculturated and non-enculturated listeners, suggesting that musical rather than cultural factors are dominant [2]. Gopala Krishna Koduri and Bipin Indurkhya results show that *ragas* are quite useful as a first step in a different direction towards content-based music recommendation. Along the way, a total of 750 subjective emotional responses to tunes composed in popular *raagas* of Carnatic music are empirically investigated to find out the long speculated relation between *raagas* and *rasas* (emotion clusters) [3]. Considering all of these works, we have brought out the new foundation to carnatic raagas in devotional songs and the proposed BAM model of fuzzy logic also suited to bring out best result.

1.1. Carnatic Music

Carnatic music (Sanskrit: *Karnataka samgita*) is a system of music commonly associated with the southern part of the Indian subcontinent, with its area roughly confined to four modern states of India: Andhra Pradesh, Karnataka, Kerala, and Tamil Nadu. It is one of two main sub-genres of Indian classical music that evolved from ancient Hindu traditions; the other sub-genre being Hindustani music, which emerged as a distinct form because of Persian and Islamic influences in North India. In contrast to Hindustani music, the main emphasis in Carnatic music is on vocal music; most compositions are written to be sung, and even when played on instruments, they are meant to be performed in *gayaki* (singing) style.
Although there are stylistic differences, the basic elements of *sruti* (the relative musical pitch), *swara* (the musical sound of a single note), *raaga* (the mode or melodic formulæ), and *tala* (the rhythmic cycles) form the foundation of improvisation and composition in both Carnatic and Hindustani music. Here A raga, the nucleus of Indian classical music, is a melodic structure with fixed notes and a set of rules characterizing a certain mood endorsed through

performance. The notes in the raga are called *swars*. The seven *swars* Sa, Re, Ga, Ma, Pa, Dha and Ni in Indian music correspond to C, D, E, F, G, A, B in Western music. Actually there are 12 notes in Western music with *Sharps* and *Flats* notes. A sharp raises a note by a half-step which is denoted by #. A flat lowers a note by a half step which is denoted by b. Therefore, these 12 notes are C, C#/Db, D, D#/Eb, E, F, F#/Gb, G, G#/Ab, A, A#/Bb and B then same **C** having twice of frequency than C. The equivalent notes in Indian classical music are S, R1, R2/G1, R3/G2, G3, M1, M2, P, D1, D2/ N1, D3/N2, N3 and **S**. The pictorial diagram is given in figure [1]. There are 72 Melakarta raagas and lot of Janya raagas within each one of Melakarta raagas.

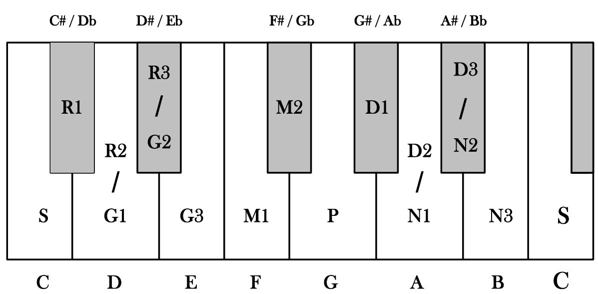

Figure 1. Note names in Harmonium

1.2. Devotional Songs

The most of the Christian devotional songs used to compose with some criteria that includes welcome ride (Entrance Hymn), Responsorial Psalm, Song for the presentation of the gifts (Offertory Hymn), Communion Hymn and finally Concluding ride (Thanks giving song). Composers may use any raagas for these songs in which we mentioned above criteria. Here, we have taken only nine raagas with accidental notes in a sample space. Finally we decided to take only three dominated raagas from each criterion among these nine raagas.

2. THEORITICAL BACKGROUND – BAM MODEL

Bidirectionality, forward and backward information flow, is introduced in neural networks to produce two-way associative search for stored stimulus-response associations (A_i,B_i).

A group of neurons forms a field. Neural networks contain many fields of neurons. F_x denotes a neuron field which contains n neurons and F_y denotes a neuron field which contains p neurons.

Neuronal Dynamical Systems The neuronal dynamical system is described by a system of first order differential equations that govern the time evaluation of the neuronal activations or membrane potentials.

$$X_i = g_i\left(X,Y,...\right), \;\; Y_j = h_j\left(X,Y,...\right)$$

Where x_i and y_j denote respectively the activation time function of the i^{th} neuron in F_x and the j^{th} neuron in F_y. The over dot denotes time differentiation, g_i and h_j are functions of X, Y etc., where $X(t) = (x_1(t),\ldots\ldots,x_n(t)$, $Y(t) = (y_1(t),\ldots\ldots,y_n(t))$ define the state of the neuronal dynamical system at time t. Additive Bivalent Models describe asynchronous and stochastic behaviour. At each moment each neuron can randomly decide whether to change state, or whether to omit a new signal given its current activation. The BAM is a non-adaptive, additive, bivalent neural network.

2.1. Bivalent Additive BAM

In neural literature, the discrete version of the earlier equations is often referred to as the Bidirectional Associative Memories or BAMs. A discrete additive BAM with threshold signal functions, arbitrary thresholds and inputs, an arbitrary but a constant synaptic connection matrix M and discrete time steps K are defined by the equations.

$$x_i^{k+1} = \sum_j^p S_j\left(y_j^k\right) m_{ij} + I_i$$

$$y_j^{k+1} = \sum_i^n S_i\left(y_i^k\right) m_{ij} + I_j$$

Where, $m_{ij} \in M$, S_i and S_j are the signal functions. They represent binary or bipolar threshold functions. For arbitrary real-valued thresholds $U = (U_1,U_2\ldots,U_n)$ for F_x neurons and $V = (V_1,V_2\ldots,V_n)$ for F_y neurons. The threshold binary signal functions corresponds neurons.

2.2. Synaptic Connection Matrices

Let us suppose that the field F_x with n neurons is synoptically connected to the field F_y with p neurons. Let m_{ij} be a synapse where the axon from the i^{th} neuron in F terminates, m_{ij} can be positive, negative or zero.

The synaptic matrix M is a $n \times p$ matrix of real numbers whose entries are the synaptic efficacies m_{ij}. The matrix M describes the forward projections from the neuronal field F_x to the neuronal field F_y. Similarly, M^T, a $p \times n$ synaptic matrix and describes the backward projections F_y to F_x.

2.3. Unidirectional Networks

These kinds of networks occur when a neuron synoptically interconnects to itself. The matrix N is $n \times n$ square matrix.

2.4. Bidirectional Networks

A network is said to be a bidirectional network if $M = N^T$ and $N = M^T$.

2.5. Bidirectional Associative Memories

When the activation dynamics of the neuronal fields F_x and F_y lead to the overall stable behaviour, the bi-directional networks are called as Bi-directional Associative Memories or BAM. A unidirectional network also defines a BAM if M is symmetric i.e. $M = M^T$.

2.6. Additive Activation Models

An additive activation model is defined by a system of $n+p$ coupled first-order differential equations that interconnects the fields F_x and F_y through the constant synaptic matrices M and N described earlier. $S_i(x_i)$ and $S_j(y_j)$ denote respectively the signal function of the i^{th} neuron in the field F_x and the signal function of the j^{th} neuron in the field F_y. Discrete additive activation models correspond to neurons with threshold signal functions. The neurons can assume only two values **ON** and **OFF**. ON represents the signal value +1 and OFF represents 0 or -1 (-1 when the representation is bipolar). The bipolar version of these equations yield the signal value -1 when $x_i<U_i$ or $y_j<V_j$.

$$\dot{x} = -A_i x_i + \sum_{j}^{p} S_j(y_j^k) m_{ji} + I_i$$

$$\dot{y} = -A_j y_j + \sum_{i}^{n} S_i(y_i^k) m_{ij} + I_j$$

The bivalent signal functions allow us to model complex asynchronous state-change patterns. At any moment different neurons can decided whether to compare their activation to their threshold. An each moment any of the 2^n subsets of F_x neurons or the 2^p subsets of F_y neurons can decide to change state. Each neuron may randomly decide whether to check the threshold conditions in the equations given above.
At each moment each neuron defines a random variable that can assume the value ON (+1) or OFF (0 or -1). The network is often assumed to be deterministic and state changes are synchronous i.e. an entire field of neurons is updated at a time. In case of simple asynchrony only one neuron makes a state change decision at a time. When the subsets represent the entire fields F_x and F_y synchronous state change results.
In a real life problem the entries of the constant synaptic matrix M depends upon the investigator's feelings. The synaptic matrix is given a weight age according to their feelings. If $x \in F_x$ and $y \in F_y$ the forward projections from F_x to F_y is defined by the matrix $M.:\{F(x_i,y_j)\} = (m_{ij})=M,\ 1<i<n,\ 1<j<p$. the backward projection is defined by the matrix M^T. $:\{F(y_j,x_i)\} = (m_{ji}) = M^T,\ 1<i<n,\ 1<j<p$.

2.7. Bidirectional Stability

All BAM state changes lead a fixed-point stability. This property holds for synchronous as well as synchronous state changes.
A BAM system (F_x, F_y, M) is bidirectionally stable if all inputs coverage to fixed point equilibrium. Bidirectional stability is a dynamic equilibrium. The same signal information flows back and forth in a bidirectional fixed point.
Let us suppose that A denotes a binary n-vector and B denotes a binary p-vector. Let A be initial input to the BAM system. Then the BAM equilibrates a bi-directional fixed point (A_i,B_j) as

$$\begin{gathered} A \rightarrow M \rightarrow B \\ A' \leftarrow M^T \leftarrow B \\ A' \rightarrow M \rightarrow B' \\ A'' \leftarrow M^T \leftarrow B' \\ \cdots \\ A_f \rightarrow M \rightarrow B_f \\ A_f \leftarrow M^T \leftarrow B_f \end{gathered}$$

Where $A', A'' \ldots$ and $B', B'' \ldots$ represents intermediate or transient signal state vectors between A and A_f , B and B_f respectively. The fixed point of a bidirectional system is time dependent. The fixed point for the initial input vectors can be attained at different times which are illustrated later. Based on the synaptic matrix M which is developed by the investigators feelings, the time at which bidirectional stability is attained also varies accordingly.

3. Description of the Problem and Finding Hidden Pattern

The raaga roots for the taken ten ragas in Carnatic notes are given below

Ra1 – SivaRanjani - S R2 G2 P D2 S
Ra2 – Natabhairavi - S R2 G2 M1 P D1 N2 S
Ra3 – Kiravani - S R2 G2 M1 P D1 N3 S
Ra4 – Karaharapriya - S R2 G2 M1 P D2 N2 S
Ra5 – Harikambhoji - S R2 G3 M1 P D2 N2 S
Ra6- DhiraShankarabharanam-S R2 G3 M1 P D2 N3 S
Ra7 – Mohanam - S R2 G3 P D2 S
Ra8 – Hamsadwani - S R2 G3 P N3 S
Ra9 – MechaKalyani - S R2 G3 M2 P D2 N3 S
Accidental note - Notes other than raaga root notes

From the Table [1] given below, we take only the following dominated raagas attributes in domain and the emotions of five different criteria of Christian devotional songs in co-domain.

P_1 – Devotion of the Listeners
P_2 – Feelings of grandeur
P_3 – Elevated to Ecstasy
P_4 – Large scope for Compositions
P_5 – Mellifluous and smooth
P_6 – Laid back majestic presentations
P_7 – Usually sing at a beginning of performance

Where P_1, P_2 and P_3 are from Natabhairavi, P_4, P_5 and P_6 from Dhira Sangarabharanam and P_7 from Hamsadhwani.

E_1 – To greet with pleasure and hospitality
E_2 – An aid to prayer
E_3 – Personal devotion and private meditation
E_4 – Acts of self surrender and oblation
E_5 – To receive or accept with satisfaction
E_6 – To meet, receive or acknowledge in a worshiped way
E_7 – Accompany and solemnize the communion of the faithful
E_8 – To join in the procession without the distraction of carrying hymnals or other worship aids
E_9 – Give thanks for the whole work of salvation

Now we have given the relations with weights by a bipartite graph among these attributes from the expert opinions and theoretical aspects.

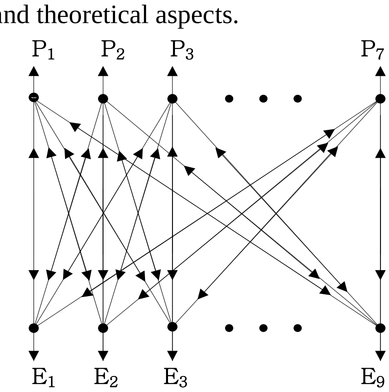

Figure 2.

As the data is an unsupervised one and involves lot of uncertainties we are given a dynamical system in matrix M and its reverse M^T with weighted values.

$$M = \begin{bmatrix} 1 & 3 & 3 & 1 & 3 & 3 & 3 & 3 & 0 \\ -1 & 3 & 3 & 2 & 3 & 3 & 3 & 3 & 0 \\ 0 & 3 & 3 & 1 & 3 & 3 & 3 & 3 & 0 \\ 2 & 1 & 1 & 3 & 2 & 2 & 2 & 1 & 3 \\ 1 & 1 & 2 & 3 & 2 & 2 & 1 & 2 & 3 \\ 2 & 1 & 1 & 3 & 1 & 1 & 1 & 1 & 3 \\ 3 & -1 & -1 & -2 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$M^T = \begin{bmatrix} 1 & -1 & 0 & 2 & 1 & 2 & 3 \\ 3 & 3 & 3 & 1 & 1 & 1 & -1 \\ 3 & 3 & 3 & 1 & 2 & 1 & -1 \\ 1 & 2 & 1 & 3 & 3 & 3 & -2 \\ 3 & 3 & 3 & 2 & 2 & 1 & 0 \\ 3 & 3 & 3 & 2 & 2 & 1 & 0 \\ 3 & 3 & 3 & 2 & 1 & 1 & 0 \\ 3 & 3 & 3 & 1 & 2 & 1 & 0 \\ 0 & 0 & 0 & 3 & 3 & 3 & 0 \end{bmatrix}$$

Let the initial vector X_1 = (1 0 0 0 0 0 0) in BAM. The effect of X_1 on the dynamical system M as follows.

X_1M = (1 3 3 1 3 3 3 3 0)
$\rightarrow$(1 1 1 1 1 1 1 1 0) = Y_1

Table 1. Domination of Carnatic raagas in Christian devotional songs

S. No	Ra-Raga / Song	Ra1	Ra2	Ra3	Ra4	Ra5	Ra6	Ra7	Ra8	Ra9	Accidental notes	Dominated Raaga
	I	Entrance Hymn										Hamsadwani
1	Archanai Malaraaga						Y					
2	Azhaikirar Yesu Aandavar						Y					
3	Anbai Kondaaduvom Irai						Y					
4	Irai Yesu Azhaippaetru								Y			
5	Sammadhamae Iraivaa			Y								
6	Thamizhaal Un Pugazh								Y			
7	Idhayangal Malarattumae								Y			
8	Isaiyil Swaram Saerththu								Y			
9	Dhinamdhorum Dhinamdhorum		Y									
10	Iraivan Nammai Azhaikkinraarae							Y				
11	Varam Kaettu Varukin	Y										
	Average	0.09	0.09	0.09	0	0	0.27	0.09	0.36	0	0	
	II	Responsorial Hymn										Natabhairavi
12	Aandavarae En Aanmaavin		Y								Y	
13	Inba Kanavondru Naan		Y								Y	
14	Amaithiyin Thoodhanaai Ennayae		Y								Y	
15	Aandavari Naan Poatriduvaen									Y		
16	Yesuvae Enniraivaa Vumadhu					Y						
17	Irai Samookamaai Naangal					Y						
18	Nirandharam Nirandharam		Y								Y	
19	Nilayillaa Vulaghu Nijamillaa		Y									
20	Oru Kodi Paadalkal Naan	Y										
21	Ungalukku Samaadhaanam						Y					
	Average	0.1	0.5	0	0	0.2	0.1	0	0	0.1	0.4	
	III	Offertory Hymn										Dhira Sangarabharanam
22	Ponnum Porulumillai Ennidaththil		Y								Y	
23	Anbin Paliyaai Aerppaai Vummai	Y										
24	Yennayae Muzhuvadhum							Y				
25	Yellaam Tharukinroam Thanthaai							Y				
26	Arppanam Arppanam Arppanamae				Y							
27	Idhayam Paadum Iniya						Y					
28	Archai Malaraai Vanthaen						Y				Y	
29	Naanae Oru Kaanikkai						Y					
30	Idho Umadhu Adimai Iraivaa		Y									
31	Yeduththukkollum Aandavarae En						Y					
	Average	0.1	0.2	0	0.1	0	0.4	0.2	0	0	0.2	
	IV	Communion Hymn										Natabhairavi with Accidental Notes
32	Uravu Ondru Ulagil Thedi						Y				Y	
33	Ovvoru Pagirvum Punitha		Y								Y	
34	Yaezhisai Naadhanae Iraivaa		Y								Y	
35	Thiruvirundhu Thiruvizhaa		Y								Y	
36	Iraivanin Vaanaga Virundhu		Y								Y	
37	Unnodu Naan Virundhunna						Y				Y	
38	Yenil Vaarum En Yesuvae		Y								Y	
39	Unnil Naan Ondraaga Uyirae					Y						
40	Yennodu Nee Pesa Vandhaai					Y						
41	Thedum Anbu Theivam					Y						
42	Theivamae Vaarum Yennilae Naan			Y							Y	
43	Yen Vaazhvil Yesuvae Ennaalum			Y							Y	
44	Vaazhvai Alikkum Vallavaa						Y					
	Average	0	0.38	0.15	0	0.23	0.23	0	0	0	0.69	
	V	Thanks Giving Song										Dhira Sangarabharanam
45	Ummai Potrukindrom Ummai						Y					
46	Nandreeyaal Thuthi Paadu						Y					
47	Nandri Koori Paaduvom Nalla						Y					
48	Ummai Thedi Vanthom sumai						Y					
49	Yennil Vantha Naadhanukku		Y								Y	
50	Alayolir Arunanai Aninthidumaam						Y					
51	Yesuvin Pinnaal Naanum Selvaen						Y					
52	Ootruth Thanneerae Endhan						Y					
53	Thanthaani Thuthppomae						Y					
54	Nandrikal Pala Koori							Y				
55	Oyaadha Karunaiyin Iraivanae						Y					
	Average	0	0.09	0	0	0	0.81	0.09	0	0	0.09	
	Membership (Net Average)	0.058	0.234	0.048	0.02	0.086	**0.362**	0.094	0.072	0.02	0.276	0.362 (Max)

$Y_1M^T = (20\ 19\ 19\ 14\ 14\ 11\ \text{-}1)$

$\rightarrow (1\ 1\ 1\ 1\ 1\ 1\ 0) = X_2$

$X_2M = (5\ 12\ 13\ 13\ 14\ 14\ 13\ 13\ 9)$

$\rightarrow (1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1) = Y_2$

$Y_2M^T = (20\ 19\ 19\ 17\ 17\ 14\ \text{-}1)$

$\rightarrow (1\ 1\ 1\ 1\ 1\ 1\ 0) = X_3\ (= X_2)$

$X_3M = (5\ 12\ 13\ 13\ 14\ 14\ 13\ 13\ 9)$

$\rightarrow (1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1) = Y_3\ (=Y_2)$

Hence the limit point is ((1 1 1 1 1 1 0),(1 1 1 1 1 1 1 1 1)).

The set of all limit points corresponding to the different input vectors

Table 2.

No	Input Vector	Limit points
1	(1 0 0 0 0 0 0)	((1 1 1 1 1 1 0),(1 1 1 1 1 1 1 1 1))
2	(0 1 0 0 0 0 0)	((1 1 1 1 1 1 0),(1 1 1 1 1 1 1 1 1))
3	(0 0 1 0 0 0 0)	((1 1 1 1 1 1 0),(1 1 1 1 1 1 1 1 1))
4	(0 0 0 1 0 0 0)	((1 1 1 1 1 1 0),(1 1 1 1 1 1 1 1 1))
5	(0 0 0 0 1 0 0)	((1 1 1 1 1 1 0),(1 1 1 1 1 1 1 1 1))
6	(0 0 0 0 0 1 0)	((1 1 1 1 1 1 0),(1 1 1 1 1 1 1 1 1))
7	(0 0 0 0 0 0 1)	((1 1 1 1 1 1 0),(1 1 1 1 1 1 1 1 1))

4. Conclusion

We have analysed the relation between properties of Carnatic raagas and emotions of Christian devotional songs where the fuzzy model BAM helped us to get the best result. The result shows that the attributes P_1, P_2, P_3, P_4, P_5 and P_6 from Properties of Carnatic ragas and E_1, E_2, E_3, E_4, E_5, E_6, E_7, E_8 and E_9 from Emotions of Devotional songs are in ON state except P_7 from the set of all limit points for each input vector and we also got the same output of limit points. So the raagas Natabhairavi, Dhira Sangarabharanam and Hamsadwani properties ultimately provide good emotions which are to greet with pleasure and hospitality, an aid to prayer, personal devotion and private meditation, acts of self surrender and oblation, to receive or accept with satisfaction, to meet, receive or acknowledge in a worshiped way, accompany and solemnize the communion of the faithful, to join in the procession without the distraction of carrying hymnals or other worship aids, give thanks for the whole work of salvation in Christian devotional songs.

So the composers can use these raagas to make devotion and peaceful life.

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