Bharatanatyam Dance Transcription using Multimedia Ontology and Machine Learning

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Abstract. Indian Classical Dance is an over 5000 years’ old multi-modal language for expressing emotions. Preservation of dance through multi-media technology is a challenging task. In this paper, we develop a system to generate parse-able representation of a dance performance. The system will help to preserve intangible heritage, annotate performances for better tutoring, and synthesize dance performances. We first attempt to capture the concepts of the basic steps of an Indian Classical Dance form, named Bharatanatyam Adavus, in an ontological model. Next, we build an event-based low-level model that relates the ontology of Adavus to the ontology of multi-modal data streams (RGB-D of Kinect in this case) for a computationally realizable framework. Finally, the ontology is used for transcription into Labanotation. We also present a transcription tool for encoding the performances of Bharatanatyam Adavus to Labanotation and test it on our recorded data set. Our primary aim is to document the complex movements of dance in terms of Labanotation using the ontology.

Keywords: Multimedia Ontology, Dance Transcription, Machine Learning, Bharatanatyam Adavu, Laban XML, Labanotation

1 Introduction

Dance is a form of art that may a tell story, set a mood, or express emotions. Indian Classical Dance (ICD) is an ancient heritage of India, which is more than 5000 years old. With the passage of time, the dance has been performed, restructured, reformulated, and re-expressed by several artists. New choreography has been composed using the basic forms. Hence, the dance forms have been associated with rich set of rules, formations, postures, gestures, stories, and other artifacts. But, till date it has been passed on to the students by the teacher, from one generation to the next, through the traditional method of Guru-Shishya Parampara, which is the typically acknowledged Indian style of education where the teacher (Guru) personally trains her / his disciple (Shishya) to keep up a continuity (Parampara) of education, culture, learning, or skills. Hence, there is a need to preserve the intangible heritage of the dance artifacts.
Recently many significant systems have been developed to preserve cultural heritage through digital multimedia technology. Preservation of the tangible heritage resources like monuments, handicrafts, and sculpture can be done through digitization, and 2D and 3D modeling techniques. Preservation of intangible resources like language, art and culture, music and dance, is more complex and requires a knowledge intensive approach. Therefore, only little work has been carried out for preservation of the dance heritage.

These dance forms embody a collection of knowledge which can be preserved either through creating digital transcription of the performances or by annotating the video recordings of performances. Analysis of dance can help convert the audio-visual information of dance into a graphical notation. Dance transcription, still a rarity, can be handy to preserve the heritage of a country like India which boasts of diverse types of classical dance forms. Transcription can also help exchanging dance ideas between performers. Another way of preserving the intangible heritage of dance is dance media annotation or to attach conceptual metadata to the collection of digital artifacts. The collection of digital artifacts with conceptual metadata can help in semantic access to the heritage collection.

Mallik et al. [7] present an ontology based approach for designing a cultural heritage repository. A Multimedia Web Ontology Language (MOWL) is proposed to encode the domain knowledge of a choreography. The suggested architectural framework includes a method to construct the ontology with a labeled set of training data and the use of the ontology to automatically annotate new instances of digital heritage artifacts. The annotations enable creation of a semantic navigation environment in the repository. The efficacy of the approach is demonstrated by constructing an ontology for the domain of ICD in an automated fashion, and with a browsing application for semantic access to the heritage collection of ICD videos.

Use of notation is another way of recording dance for future use. A system of notation is required for recording the details of postures and movements in domain of dance. Labanotation [2] is a widely used notation system for recording human movements in terms of graphical primitives and symbols. Karpen [4] first attempted to manually encode the movements of Bharatanatyam on paper using Labanotation. It has been demonstrated by examples that the body movement, space, time, and dynamics of the ICD, in particular Bharatanatyam, can be described through Labanotation. Hence it is argued that the Labanotation, coupled with video filming, is a good way to record ICD. According to the author, hand gestures can also be easily implemented in Labanotation together with palm facing and specification of the quality of movement. However, no attempt was made in this paper to automate the process and for the next about three decades no work was done in transcribing ICD in Labanotation. Some research on dance preservation using notation has been carried out in other dance forms like Thai dance, Contemporary dance etc. Raheb et al. [1] use Web Ontology Language (OWL) to encode the knowledge of dance. The semantics of the Labanotation system is used to build elements of the ontology. Tongpaeng et al. [9] propose a system to archive the knowledge of Thai dance using Labanotation and then
use the score of the notation to represent the dance in 3D Animation. Till date automatic generation of Labanotation from the recorded dance video has not been attempted.

This work has been inspired by the idea of musical notations. Similar dance transcription systems may be useful in several way. The system can generate parse-able representation of a dance performance, help to preserve intangible heritage, help to annotate performances for better tutoring, and can be used as a front-end for dance synthesis. We first attempt to capture the concepts in Bharatanatyam Adavus in an ontological model. At the top level, a Bharatanatyam Adavu can be expressed as a dance (sequence of visual postures) accompanied by music. Further, we identify the concepts of audio and video structures of Bharatanatyam Adavu. We next build an event-based low-level model that relates the ontology of Adavus to the ontology of multi-modal data streams (RGB-D of Kinect in this case) for a computationally realizable framework. An event denotes the occurrence of an activity (called Causal Activity) in the audio or the video stream of an Adavu. The events of audio, video and their synchronization, thus, are related to corresponding concepts of the ontological model. We use this ontology and event characterization for transcription into Labanotation using Laban ontology. We also present a transcription tool for encoding the performances of Bharatanatyam Adavus to Labanotation and test it on our recorded data set. Our aim is to examine the ways in which Labanotation can be used for documenting the dance movements.

2 Indian Classical Dance: Bharatanatyam and its Adavus

We introduce the domain of Bharatanatyam Adavu in the context of our knowledge capture and heritage preservation scheme of the article for the ease of understanding the through the entire paper.

Bharatanatyam is one of the eight\textsuperscript{1} Indian Classical Dance forms. Like most dance forms, Bharatanatyam Adavu too is deeply intertwined with music. It is usually accompanied by instrumental (Tatta Kazhi\textsuperscript{2}, Mridangam, Flute, Violin, Veena, etc.) and / or vocal music (Carnatic style – with or without lyrics) called Sollukattu. Adavus are the basic units of Bharatanatyam that are combined to create a dance performance. An Adavu involves various postures and gestures of the body including torso, head, neck, hands, fingers, arms, legs and feet, and eyes. While performing Adavus, the dancer stamps, rubs, touches, slides on the ground in different ways in synchronization with the Sollukattu. There are 15 basic Adavus in Bharatanatyam – most having one or more Variants. In total, we deal with 58 Adavu variants. There exists a many-to-one mapping from the Adavus to the Sollukattus.

\textsuperscript{1} ICD has eight distinct styles as recognized by the Ministry of Culture, Government of India: namely, Bharatanatyam, Kathak, Odissi, Kathakali, Kuchipudi, Manipuri, Mohiniyattam, Satriya.

\textsuperscript{2} A wooden stick is beaten on a wooden block to produce instrumental sound.
2.1 Sollukattus and Bolas – the Music of Adavus

Bharatanatyam is deeply intertwined with music. It is usually accompanied by Instrumental (Tatta Kashi, Mridangam, Flute, Violin, Veena, etc.) and/or Vocal music (Carnatic style – with or without lyrics). The music is strung together in sequences to create different rhythmic patterns, called Taalam\(^3\) to accompany dance performances. A repeated cycle of Taalam consists of a number of equally spaced beats, which are grouped into combinations of patterns. Time interval between any two beats is always equal. The specific way they mark the beats (by tapping their laps with their fingers, palm, and back of the hand; or by a specific instrument) are determined by these patterns of the beats or the Taalam.

Table 1. List of Sollukattus with bol compositions

| Sollukattu | # Beats | Description of Bol(s) |
|------------|---------|-----------------------|
| Joining A  | 8       | tat dhit ta [B] tat dhit ta [B] |
| Joining B  | 6       | [dhit dhit] tei [dhit dhit] tei [dhit dhit] tei [dhit dhit] tei |
| Joining C  | 8       | tei tei [dhit dhit] tei tei tei [dhit dhit] tei |
| KUMS       | 6       | tan gadu tat tat dhin na tan gadu tat tat [dhit na] |
| Mettu      | 8       | tei hat tei hi tei hat tei hi |
| Nattal A   | 8       | tat tei tam [B] dhit tei tam [B] |
| Nattal B   | 8       | [tat tei] tam [dhit tei] tam [tat tei] tam [dhit dhit] tei |
| Tattal     | 8       | tat tei ta ha dhit tei ta ha |
| Natta      | 8       | [tei yum] tat tat tei yum ta [tei yum] tat tat |
| Patkai     | 8       | [dhit tei da] [ta tei] [dhit tei da] [ta tei] |
| Patka      | 8       | [tei tei] tam dhit tei tam |
| Serika     | 8       | tei a tei e a tei e |
| Tatia A    | 8       | [tei ya] tei [tei ya] tei [tei ya] tei [tei ya] |
| Tatia B    | 6       | tei tei tam tei tam |
| Tatia C    | 8       | [tei ya] [tei ya] [tei ya] tei [tei ya] [tei ya] [tei ya] |
| Tatia D    | 8       | tei tei [tei tei] tam tei tei [tei tei] tam |
| Tatia E    | 8       | tei tei tam [B] tei tei tam [B] |
| Tatia F    | 8       | tei tei tat tat tei tam |
| Tatia G    | 6       | tei tei tei tei [dhit dhit] tei |
| TTD        | 8       | [tei tei] [dhit ta] [dhit tei] [dhit ta] [tei tei] [dhit tei] [dhit ta] [dhit ta] |
| Tirama A   | 12      | [tat ta] jham [ta ri] ta [B] jham [ta ri] jang [ta ri] tei [B] |
| Tirama B   | 12      | [tat ding] gin na tom [tak k] [tat ding] gin na |
| Tirama C   | 12      | [ki ta ta ka] dha ri ki ta tom [ki ta ta ka] dha ri ki ta |

- Multiple bols at the same beat are enclosed within []
- [B] stands for a beat without any bols – typically called stick-beat
- KUMS, Mettu, Nattal, Tattal, and TTD stand for Kartati–Utsanga–Mandi–Sarikkal, Kuditta Mettu, Kuditta Nattal, Kuditta Tattal, and Tei Tei Dhatta respectively

Taalams necessarily synchronize the movements of various parts of the body with the music through a structured harmonization of four elements, namely – (a) Rhythmic beats of Taalam, (b) Mridangam beats from percussion, (c) Musical notes or Swaras\(^4\), and (d) Steps of the Adavus. It may be noted that a

\(^3\) Taalam is the Indian system for organizing and playing metrical music.

\(^4\) Swaras, in Sanskrit, connotes a note in the successive steps of the octave.
number of different Taalams are used in Bharatanatyam. The Taalams\textsuperscript{5} commonly used in Adavu are – Adi taalam (8 beats’ pattern) and Roopakam taalam (6 beats’ pattern). Finally, a Taalam is devoid of a physical unit of time and is acceptable as long as it is rhythmic in some temporal unit. With a base time unit, however, Bharatanatyam deals with three speeds, called Kaalam or Tempo. The Taalams are played mainly in 3 different tempos – Vilambitha Laya or slow speed, Madhya Laya (double of Vilambitha Laya) or medium speed, and Drutha Laya (quadruple of Vilambitha Laya) or fast speed.

A phrase of rhythmic syllables (Sollukattu), is linked to specific units of dance movement in an Adavu. A Sollukattu\textsuperscript{6} is a specific rhythmic musical pattern created by combination of instrumental and vocal sounds. Traditionally, a Tatta Kazhi (wooden stick) is beaten on a Tatta Palahai (wooden block) for the instrumental sound and an accomplice of the dancer speaks out a distinct vocalization of rhythm, like tat, tei, ta etc., called Bol\textsuperscript{7}. In a Sollukattu, both the instrument and the voice follow in sync to create a pattern of beats. Every beat is usually marked by a synchronous beating (instrumental) sound, though some beats may be silent. In some cases, there may be beating (instrumental) sound at positions that are not beats (according to the periodicity). The list of Sollukattus are given in Table 1. As Adavus are performed along with the rhythmic syllables of a Sollukattu that continues to repeat in cycles. Rhythm performs the role of a timer (with beats as temporal markers). Between the interval of beats, the dancer changes her posture.

2.2 Adavus – the Postures and Movements

Adavus are the basic unit of Bharatanatyam that are combined to form a dance sequence in Bharatanatyam. Adavus form the foundation stone on which the entire Nritta rests. It involves various postures, gestures of the body, hand, arms, feet, and eyes\textsuperscript{8}. While performing Adavus the dancer stamps, rubs, touches, slides on the ground in different ways in synchronization with the Sollukattu (bol) or the syllables used. The Adavus are classified according to the rhythmic syllables on which they are based and the style of footwork employed. According to Kalakshetra school of training there are 15 Adavus. Most Adavus have two or more Variants. Variants of an Adavu bear similarity of intent and style, but differ in details. A total 58 Adavus and 23 Sollukattus are used in Kalakshetra\textsuperscript{9}.

\textsuperscript{5} Adavus can be performed in all 7 taalams as well; but the rest are less popular.
\textsuperscript{6} ‘sollukattu’ = sollam (syllables) + kattu (speaking). A Sollukattu means a phrase of rhythmic syllables linked to specific units of dance movement (Adavu).
\textsuperscript{7} Boks (or bolna = to speak), are mnemonic syllables for beats in the taalam.
\textsuperscript{8} Current work does not consider hand and eye movements for limitations of sensors.
\textsuperscript{9} There are four major styles of Bharatanatyam – Thanjavur, Pandanallur, Vazhuvoor, and Mellatur. Kalakshetra, promulgated by the Kalakshetra Foundation founded by Rukmini Devi, is the modern style of Bharatanatyam and is reconstructed from Pandanallur style.
The details are listed in Table 2. Every (variant of an) Adavu uses a fixed Sollukattu while a given Sollukattu may be used in multiple Adavus. Each posture of Adavus is a combination of leg support (Mandalam), legs position (Pada Bheda), arms position (Bahu Bheda), head position (Shiro Bheda), hand position (Hasta Mudras), neck position (Griba Bheda), eyes position (Drishti Bheda).

### Table 2. List of Adavus with accompanying Sollukattu

| # | Name               | Taalam          | Sollukattu |
|---|--------------------|-----------------|------------|
| 1 | Joining            | Adi             | Joining A  |
|   | Joining 1          |                 |            |
|   | Joining 2          | Adi             | Joining B  |
|   | Joining 3          | Adi             | Joining C  |
| 2 | Kati or Kartari    | Kati or Kartari | Hoopakam   |
|   | Kati or Kartari 1  |                 | KUMS       |
| 3 | Kuditta Metta      | Kuditta Metta   | Adi        |
|   | Kuditta Metta 1–4  | Adi             | Kuditta Metta |
| 4 | Kuditta Nattal     | Kuditta Nattal  | Adi        |
|   | Kuditta Nattal 1–3 | Adi             | Kuditta Nattal A |
|   | Kuditta Nattal 4–5 | Adi             | Kuditta Nattal B |
|   | Kuditta Nattal 6   | Adi             | Kuditta Nattal A |
| 5 | Kuditta Tattal     | Kuditta Tattal  | Adi        |
|   | Kuditta Tattal 1–3 | Adi             | Kuditta Tattal |
| 6 | Mandi              | Mandi 1–2       | Hoopakam   |
|   |                   |                 | KUMS       |
| 7 | Natta              | Natta 1–8       | Adi        |
|   |                   |                 | Natta      |
| 8 | Paikkal            | Paikkal 1–3     | Adi        |
|   |                   |                 | Paikkal    |
| 9 | Pakka              | Pakka 1–4       | Adi        |
|   |                   |                 | Pakka      |
|10 | Sarika             | Sarika 1–4      | Adi        |
|   |                   |                 | Sarika     |
|11 | Sarikkal           | Sarikkal 1–3    | Hoopakam   |
|   |                   |                 | KUMS       |
|12 | Tatta              | Tatta 1–2       | Adi        |
|   |                   |                 | Tatta A    |
|   |                   | Adi             | Tatta B    |
|   |                   | Hoopakam        | Tatta 3    |
|   |                   |                 | Tatta C    |
|   |                   | Adi             | Tatta D    |
|   |                   | Hoopakam        | Tatta 5    |
|   |                   |                 | Tatta E    |
|   |                   | Adi             | Tatta 6    |
|   |                   | Hoopakam        | Tatta 7    |
|   |                   |                 | Tatta F    |
|   |                   | Adi             | Tatta 8    |
|13 | Tei Tei Dhatta     | Tei Tei Dhatta  | Adi        |
|   |                   |                 | Tei Tei Dhatta |
|14 | Tirmana            | Tirmana 1       | Adi        |
|   |                   | Hoopakam        | Tirmana 2  |
|   |                   |                 | Tirmana A  |
|15 | Utsanga            | Utsanga 1       | Adi        |
|   |                   | Hoopakam        | Utsanga 1  |

* KUMS stands for Kartati–Utsanga–Mandi–Sarikkal

Since Adavus are elementary units and used for training, each Adavu has a specific purpose (as shown is Table 3). For example, Tatta Adavus focus on striking of the floor with foot. The body remains in a posture called Arai\(\text{n}\)m\(\text{a}\)nd\(\text{i}\) and the feet, by rotation, strike the floor alternately with the sole. There are 8 variants of Tatta Adavu. The features of the Variant 1 of Tatta Adavu (say, Tatta 1) are – (a) Strike on the floor, (b) Heel to touch hip during strike, (c) No hand gesture, and (d) No movements. The Sollukattu used in Tatta 1 is \textit{tei a tei} (say, Tatta-A). This follows the Adi Taalam or 8 beats’ pattern as shown in Table 4. The bols on each beat are shown in three different tempos.

The posture of a dancer is synchronized with the beats. The synchronized postures with beats are shown in Figure 4. Here, the dancer strikes her left and right foot with the beats in rotation.

Like Tatta 1, all Adavus are combinations of:
Table 3. Purpose of various Adavus

| Adavu          | Purpose of the Adavu                                                                 |
|----------------|------------------------------------------------------------------------------------|
| Joining        | Simple connecting Adavus to be used while building longer sequences of postures.   |
| Kati or Kartari| Paidhal itself includes a variety of leaps and may also be coupled with spins      |
|                | (Bramhari). It also includes the famous Kartari (Scissors) adavu where the        |
|                | movement of the hand and feet trace crisscross patterns in space.                 |
| Kuditta Mettu  | Jumping on the toes and then striking the heels                                    |
| Kuditta Nattal | Striking the floor by leg, jumping on toes, stretching legs and hands and also    |
|                | circular movement of hand                                                         |
| Kuditta Tattal | Striking the floor, jumping on toes, stretching hands, circular movements of      |
|                | hands, neck and head with the bending of torso and waist and hand movements        |
|                | define different planes in space                                                  |
| Mandi          | Mandi in some Indian languages refers to area around the thigh and knee. In       |
|                | some instance we can refer it to a bent knee. For example, Arajamandi is where   |
|                | the knee is half bent. Muzhumandi or Poorna Mandala is where the knee is          |
|                | fully bent. In Mandi adavus we make use of the Muzhumandi position often.         |
|                | Steps could vary from jumps in Poorna Mandala to jumping and touching one knee    |
|                | on the floor.                                                                      |
| Natta          | Stretching of legs                                                                  |
| Pakkal         | Pakkal (Paidhal or Paschal) is a Tamil term that means to leap. It differs         |
|                | from the Kuditta Mettu in the sense, the dancer while doing the Pakkal covers    |
|                | space, whereas in Kuditta Mettu she / he jumps in the same spot. A very           |
|                | graceful step in itself, Pakkal is usually seen at the end of Korvai (a string of |
|                | Adavus) as part of Ardhis.                                                          |
| Pakka          | Moving towards sides                                                                |
| Sarika         | Sarika means a thing of beauty or nature.                                           |
| Sarikkal       | Sarikkal means to slide: Here as one foot is lifted and placed the another foot   |
|                | slides towards it.                                                                 |
| Tattu          | Striking the floor with feet                                                        |
| Tei Tei Dhatta | Use of half and full seating, stretching legs and hand, jumping with linear and    |
|                | circular movements of hands                                                        |
| Tirmana        | Tirmana (or Teermanam means to conclude) or an ending or a final stage. Thus the   |
|                | steps in these adavus are used to end a dance sequence or jathis. It is done in   |
|                | a set of three steps or repeated thrice.                                            |
| Utsanga        | Use of different hand position to enhance the stretching on half seating, straight|
|                | standing, jump on heels, striking the floor. Also use of linear and circular      |
|                | movements of waist and stretching of hands.                                         |

Source: [10] and personal communication with Debaldev Jana

Table 4. Beat pattern of Tattu 1 (Tattu Adavu Variant 1) in Adi Taalam

| Beats | Speed | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|-------|-------|---|---|---|---|---|---|---|---|
|       |       | tei a| tei | tei a| tei | tei a| tei | tei a| tei |
| 1<sup>st</sup> |       | tei | tei a| tei a| tei | tei | tei a| tei | tei |
| 2<sup>nd</sup> |       | tei a| tei a| tei a| tei | tei a| tei | tei a| tei a|
| 3<sup>rd</sup> |       | tei a| tei a| tei a| tei | tei a| tei | tei a| tei a|

Time Measure: Adi Taalam

- Position of the legs (Sthanakam) / Posture of standing (Mandalam): Adavus are performed in postures that are (Figure 2) – (a) Samapadam or the standing position, (b) Arajamandi / Ardh Mandalam or the half sitting posture, and (c) Muzhumandi or the sitting posture.
- Jumps (Utplavana): Based on the mode of performances Utplavanas are classified into Alaga, Kartari, Asva, Motita, and Kripalaya.
Right Strike  Left Strike  Right Strike  Left Strike
  tei a (beat 1)  tei (beat 2)  tei a (beat 3)  tei (beat 4)

Right Strike  Left Strike  Right Strike  Left Strike
  tei a (beat 5)  tei (beat 6)  tei a (beat 7)  tei (beat 8)

Fig. 1. Example performance of Tatta 1 (Tatta Adavu Variant 1)

Samapadam  Araimandi  Muzhumandi
(Standing)  (Half Sitting)  (Full Sitting)

Sources: Leg Postures in Bharatanatyam by Nysa Dance Academy
https://nysadance.com.wordpress.com/2015/09/26/leg-posture-araimandi-or-ardhamandala/

Fig. 2. Three Mandalams (types of leg support) of Bharatanatyam

Walking Movement (Chari): Chari are used for gaits. According to Abhinayadarpana, there are eight kinds of Charis – Chalana, Chankramana, Sarana, Vehini, Kuttana, Luhita, Lolita, and Vishama Sanchara.

Hand Gestures (Nritta Hastas): Bharatanatyam primarily uses two types of Hasta Mudras (Figure 3) that play a significant role in communication – 28 single hand gestures (Asamyutha Hasta) and 23 combined (both) hand gestures (Samyutha Hasta). There are twelve major hand gesture for Adavus – Pataka, Triptaka, Ardhachandra, Kapittha, Katakamukha, Suchi Musthi, Mrigasirsha, Alapadma, Kaetarimukha, Shikhara, and Dola.

10 Few other types like Nritya Hasta are used at times.
In Bharatanatyam, *Adavu* is used in dual sense. It either denotes just the dance part (postures and movements) or the dance and the accompanying music together. To maintain clarity of reference, in this paper, we refer to the dance simply by *Adavu* and the composite of dance and music by *Bharatanatyam Adavu*.

(a) Sets of *Asamyutha Hasta Mudras*

(b) Sets of *Samyutha Hasta Mudras*

*Image Source: https://grade1.weebly.com/theory.html*

*Fig. 3. Hasta Mudras of Bharatanatyam*
3 Object-based Modeling of Adavus

To express the ontology we follow an extended object-based modeling framework comprising a set of classes (Table 5), a set of instances (Table 6), and a set of relations (Table 7). Classes are used to represent generic as well as specific concepts. These can be Abstract or Concrete. A concrete class has one or more instances while an abstract class has one or more specialized classes. Relations are usually binary and are defined between two classes, between a class and an instance, or between two instances.

### Table 5. List of Classes for the ontology of Bharatanatyam Adavu

| Class                          | Type  | Remarks                                                                 |
|-------------------------------|-------|-------------------------------------------------------------------------|
| Sollukattu                    | Concrete | The music (audio) of Adavus (Table 4)                                   |
| Adavu                         | Abstract | The movements (video) of Adavus (Table 2)                               |
| Tatta Adavu, Natta Adavu, · · · | Concrete | Types of Adavus (Table 2)                                               |
| Carnatic Music                | Abstract | The style of Bharatanatyam music                                        |
| Sequence                      | Abstract | Ordered list of elements of one kind                                    |
| Beat                          | Abstract | Basic unit of time – an instance on timescale                            |
| Bol                           | Concrete | Mnemonic syllable or vocal utterances (Table 8)                         |
| Posture                       | Abstract | Standing or sitting position of a dancer                                 |
| Tandem                        | Concrete | Rhythmic pattern of beats                                               |
| Tempo                         | Concrete | Beats per minute – defines speed                                        |
| Instrumental Strike           | Concrete | Beating of a percussion                                                 |
| Position (Time Stamp)         | Concrete | Instant of time                                                         |
| Key Posture                   | Concrete | Momentarily stationary posture (Figure 1)                               |
| Transition Posture            | Abstract | Non-stationary posture                                                  |
| Trajectorial Transition Posture| Concrete | Transitions along a well-defined trajectory                             |
| Natural Transition Posture    | Concrete | Natural posture transitions by the dancer                                |
| Leg Support (Mandalom)        | Concrete | Ways to support the body (Figure 2)                                     |
| Legs Position (Pada Bheda)    | Concrete | Positions of both legs in Bharatanatyam                                |
| Arms Position (Bahu Bheda)    | Concrete | Positions of both arms in Bharatanatyam                                 |
| Head Position (Shiro Bheda)   | Concrete | Positions of head in Bharatanatyam                                     |
| Neck Position (Gbha Bheda)    | Concrete | Positions of neck in Bharatanatyam                                     |
| Eyes Position (Drishti Bheda)  | Concrete | Eye movements depicting navarasa                                        |
| Hands Position (Hasta Mudra)  | Abstract | Positions of both hands in Bharatanatyam                               |
| Single Hand Gesture           | Concrete | Asamyukta Hasta Mudras (Figure 3)                                       |
| Double Hand Gesture           | Concrete | Samyukta Hasta Mudras (Figure 5)                                        |
| Left Leg (Formation)          | Concrete | Left leg in Pada Bheda (Table 6)                                        |
| Right Leg (Formation)         | Concrete | Right leg in Pada Bheda (Table 6)                                       |
| Left Arm (Formation)          | Concrete | Left arm in Bahu Bheda (Table 10)                                       |
| Right Arm (Formation)         | Concrete | Right arm in Bahu Bheda (Table 10)                                      |
| Left Hand (Formation)         | Concrete | Left hand in Hasta Mudra (Table 11)                                     |
| Right Hand (Formation)        | Concrete | Right hand in Hasta Mudra (Table 11)                                    |

3.1 Ontology of Bharatanatyam Adavus – Top Level

At the top level, a Bharatanatyam Adavu can be expressed simply as a dance (Adavu) accompanied and driven by (isAccompaniedBy) music (Sollukattu) (Figure 1). In other words, the musical meter\(^{11}\) of an Adavu is called a Sollukattu which is a sequence of beats / bol s. An Adavu is a sequence of postures. We also note that Sollukattu is a form of Carnatic Music.

\(^{11}\) The meter of music is its rhythmic structure.
Table 6. List of Instances for the ontology of Bharatanatyam Adavu

| Class/Instance                                                                 |
|-------------------------------------------------------------------------------|
| • Sollukattu: Tatta_A, ···, Tatta_G, Natta, Kuditta Mettu                     |
| • Adavu: Tatta 1, ···, Tatta 8, Natta, Kuditta Mettu                         |
| • Bot: tei, yum, tat, ···                                                    |
| • Taalam: Adi Taalam, Roopakam Taalam                                      |
| • Tempo (Laya): Vilambit Laya, Madhay Laya, Drut Laya                        |
| • Spinal Bending (boolean)                                                   |
| • Key Postures: Natta1P1, Natta1P2, Natta1P3, ···                            |
| • Arms Position: Natyarambhe [S], Natyarambhe [M], ···                       |
| • Head Position: Samam, Left Paravrittam, Right Paravrittam, ···             |
| • Hands Position: Tripataka [S], ···                                         |
| • Left / Right Leg (Formation): Aayata, Anchita, ···                         |
| • Left / Right Arm (Formation): Natyarambhe, Kunchita Natyarambhe, ···       |
| • Left / Right Hand (Formation): Tripataka, ···                              |

Remarks:
- [S]: Denotes symmetric ([S]) positions between left and right limbs
- [M]: Denotes asymmetric positions between left and right limbs and its mirror ([M])
- Instances of Neck Position, Eyes Position, and Double Hand Gestures are not considered

Table 7. List of (Binary) Relations for the ontology of Bharatanatyam Adavu

| Relation               | Domain     | Co-Domain | Remarks                                                                 |
|------------------------|------------|------------|-------------------------------------------------------------------------|
| is_a                   | Class      | Class      | Specialization / Generalization or a hierarchy of Object-based Modeling. This is used to build the taxonomy. For example, Tatta Adavu is_a Adavu. |
| has_a                  | Class      | Instance   | Composition or has_a hierarchy of Object-based Modeling. This is used to build the partonomy. For example, Sollukattu has_a Taalam. |
| isInstanceOf           | Instance   | Class      | Distinct instances of a class                                           |
| isAccompaniedBy        | Class      | Class      | isAccompaniedBy captures the association between video and audio streams. Hence, Adavu isAccompaniedBy Sollukattu. |
| isSyncedWith           | Class      | Class      | Expresses high-level synchronization – between audio and video streams. Every Adavu isSyncedWith a unique Sollukattu. |
| isSequenceOf           | Class      | Class      | isSequenceOf builds a sequence from elements of the same type. For example, every Sollukattu (Adavu) has_a a sequence of beats (postures) constructed from beat (postures) by isSequenceOf relation. isFollowedBy is a dual of this relation. |
| isAccentedBy           | Class      | Class      | A beat isAccentedBy a bol.                                              |
| isFollowedBy           | Class      | Class      | Ordering of audio events (like beats) or video events (like postures) – Event $E_1$ is isFollowedBy event $E_2$. isSequenceOf is a dual of this relation. |
| triggers               | Instance   | Instance   | Expresses low-level synchronization – between audio and video events. Hence, a beat triggers a posture as the dance is driven by the music. |
| repeats                | Class      | Class      | Once a taalam completes a bar, it may repeat itself.                     |

Elaborating on the basic concept of Adavus, we show in Figure 5 that there are several specializations of Adavus like Tatta Adavu or Natta Adavu having
instances Tatta Adavu 1, · · ·, Tatta Adavu 8 etc. and there are several instances of Sollukattus like Tatta A, · · · Kuditta Mettu, etc. Specifically, every Adavu is synchronized with (isSyncedWith) a unique Sollukattu.

3.2 Ontology of Sollukattus

Next, we elaborate the ontology of a Sollukattu (Section 2.1 in Figure 6). A Sollukattu is performed in a Taalam that designates a specific pattern of rhythm. A Taalam is composed of a sequence of beats (isSequenceOf) going at a certain tempo (speed). At the end of the sequence of beats (or the bar), the Taalam repeats itself. A tempo corresponds to the speed of the rhythm which may be
carried out in one of the three speeds (Laya) – slow, medium, and fast. Adi Taalam and Roopakam Taalam are the typical rhythms used in Bharatanatyam.

A beat is an instant in time that may be marked by beating of a stick and optionally accented by a bol. Hence, it has a temporal position (time stamp), an instrumental strike (for example, beating of Tatta Kazhi), and a bol like tei, yum, tat, ··· (vocabulary of Bols by Bharatanatyam experts is given in Table 8).

Table 8. Bol vocabulary of Sollakattus

| Sl. # | Bol   | Sl. # | Bol   | Sl. # | Bol   |
|-------|-------|-------|-------|-------|-------|
| 1     | a     | 12    | ha    | 23    | tak   |
| 2     | da    | 13    | hat   | 24    | tam   |
| 3     | dha   | 14    | hi    | 25    | tan   |
| 4     | dhat  | 15    | ing   | 26    | tat   |
| 5     | dhi   | 16    | jam   | 27    | tei   |
| 6     | dhin  | 17    | lax   | 28    | tom   |
| 7     | dhat  | 18    | ki    | 29    | tta   |
| 8     | ding  | 19    | la    | 30    | ta    |
| 9     | e     | 20    | ta    | 31    | yum   |
| 10    | gada  | 21    | ri    | 32    | Stick Beat |
| 11    | gin   | 22    | a     |       |       |

*Stick Beat* is treated as a pseudo-bol. The bols shown in the table are typical as Bharatanatyam does not follow a strictly fixed set of bol.
3.3 Ontology of Adavus

We elaborate the ontology of an Adavu (Section 2.2) in Figure 7. An Adavu is created by a sequence of Postures and intervening Movements like Utplavana (Jumps), Chari (Walking), or Karana (synchronized movement of hands and feet). A posture may be a Key Posture or a Transition Posture. A Key Posture is defined as a momentarily stationary pose taken by the dancer with well-defined positions for the Legs (Pada Bheda), the Arms (Bahu Bheda), the Head (Shiro Bheda), the Neck (Griba Bheda), the Eyes (Drishti Bheda), and the Hands (Hasta Mudra). Every Key Posture is also defined with a specific Leg Support and Spinal Bending to support and balance the body. A Transition Posture, in turn, is a transitory pose (ill-defined, at times) between two consecutive Key Postures in a sequence or a pose assumed as a part of a movement. It may be Trajectorial or Natural. While a Trajectorial Transition Posture occurs in a well-defined trajectory path of body parts, a Natural Transition Posture may be suitably chosen by a dancer to move from one Key Posture to the next.

![Fig. 7. Ontology of Adavus](image)

In the current work, we focus only on Key Postures and do not model and/or analyze movements and transitions. Hence, we do not elaborate the ontology for Transition Postures or movements. However, the concept of Key Postures are detailed in Figure 8.

12 Karanas (‘doing’ in Sanskrit) are the 108 key transitions described in Natya Shastra.
Vocabulary of Positions and Formations

To elaborate the ontology for a Key Posture, we introduce the notions of positions and formations of constituent limbs or body parts. A formation describes the specific manner in which a body part is posed in the posture. For body parts that occur in pair (like leg, arm, hand, eye), the combined formation of the individual (left and right) parts define a position. For the rest (like head, neck) position and formation are taken to be synonymous. Accepted nomenclature (as identified by the experts) exists for many positions / formations of most of the body parts in Bharatanatyam. Naturally, we adopt those. For the rest, we assign names based on crisp descriptors of the positions. We observe that the postures mostly are distinguishable based on the four major body parts – leg, arm, head, and hand. Hence, we have not considered the eyes and the neck in building the posture ontology.

In Table 9, we list the vocabulary for formations of left and right legs as well as their combined legs positions. Some of the positions are asymmetric in which the left and the right leg assume different formations. For example, if the left leg is in Anchita formation and the right leg is in Samapadam formation, the combined legs position is named as Ardha Prenkhanam. Naturally, every asymmetric position has a position which is a mirror image of the other one, marked by [M] (Mirror), where the formations of the legs are swapped. That is, in Ardha Prenkhanam [M], the right leg is in Anchita formation and the left leg is in Samapadam formation. In the table, we have listed only one of these mirrored positions. Remaining leg positions are symmetric in which both legs assume the same formation. In such cases, the position is marked with an [S] (Symmetric) and the same name is used for the formation and the position. Hence in Aayata [S] position, both legs are in Aayata formation.

Table 9. Vocabulary of formations and positions of legs (Pada Bheda)

| Left Leg Formation | Right Leg Formation | Leg Position |
|--------------------|---------------------|--------------|
| **Asymmetric Positions** | | |
| Anchita | Samapadam | Ardha Prenkhanam |
| Aayata | Samapadam | Back Svasatkam |
| Agrata Sanchara | Samapadam | Chalan Chari |
| Aayata | Samapadam | Diagonal Anchita |
| Bend On Knee | Support | Ekapadam |
| Aayata | Front Anchita | Front Prenkhanam |
| Aayata | Front Swastikam | Front Swastikam |
| Aayata | Prerita | Prerita |
| Parsasuchi | Rixamasuchi | Garudamandalam |
| Aayata | Forward / Side Low | Lolita Chari |
| Aayata | Anchita | Prenkhanam |
| Aayata | Side Middle / Low | Prenkhanam Above Floor |
| Aayata | Kunchita | Aaleeda (M = Pratyaaleeda) |
| Aayata | Kunchita | Pratyaaleeda |
| **Symmetric Positions** | | |
| Aayata | Anchita | Ekapadam Bhramari |
| Samapadam | Motita Mandal | Side Chankramanang |
| Kuttana | Slip With Left Knee | Chankramanang |
| Parswa Aayata | Slip With Right Knee | Back Chankramanang |
In Table 10 we list the vocabulary for the formations of the arms. Either arm can assume any of these formations. In case of arms, no specific names are used for combined arms positions. Hence, they are referred to with the names of both the formations if they are different. For example, if the left arm is in Kunchita Natyarambhe formation and the right arm is in Natyarambhe formation, the combined arms position is named as Natyarambhe–Kunchita Natyarambhe. If, however, both formations are same, we name the position with an [S]. Hence Natyarambhe [S] has Natyarambhe formation for both arms. In Table 11 we list the vocabulary for the formations of the head. Naturally, there is no position descriptor here. Next we list the vocabulary for the formations of the hands (hasta mudra) in Table 12. Like arms, these are also denoted with formations of single hands only and combined hands position is similarly named. It may be noted that the vocabulary listed here is a subset of Asamyutha Hasta or single hand gestures as commonly observed in the Adavus. We do not consider Samyutha Hasta or combined (both) hand gestures in building the vocabulary.

Table 10. Vocabulary of formations of arms (Bahu Bheda)

| Above Head Natyarambhe (Joined) | Anchita | Anchita Above Left Ear | Anchita Above Right Ear | Ardha Vithi | Backward High | Backward Low | Backward Middle | Cross Kunchita |
|---------------------------------|---------|------------------------|-------------------------|-------------|---------------|--------------|----------------|---------------|
| Diagonal High                   | Diagonal Middle | Elbow Down Anchita      | Forward High             | Forward High Above Head | Forward Low  | Forward Middle | Front Natyarambhe | Kunchita     |
| Kunchita                       | Kunchita Above Shoulder | Left Diagonal High | Natyarambhe | Right Diagonal High | Right Diagonal Middle | Side High | Side High Natyarambhe | Side Low     |

Ontology of Key Postures We elaborate the ontology of Key Postures in Figure 8. Consider the Legs Positions. For the Prenkhanam Legs Position in Natta1P2 in the figure, the left leg makes the Aayata (bent at knee) and the right leg makes Anchita formation (straight and stretched). Prenkhanam [M] is a mirror image position of Prenkhanam where the formations of the two legs are swapped. Natta1P3 is a mirrored posture of Natta1P2 and has Prenkhanam [M] for the legs positions. With symmetry Natta1P1 has Aayata [S] legs position.

Consider instances of 3 key postures – Natta1P1, Natta1P2, and Natta1P3 – of Natta 1 Adavu. For example, for instance Natta1P1, we have Legs Position = Aayata [S], Arms Position = Natyarambhe [S], Hands Position = Tripataka [S], and Head Position = Samam.

We identify 361 distinct postures and 48 distinct movements in the 58 Adavus.

3.4 Ontology of Audio-Visual Sync between Sollukattu & Adavu

With the ontology of music (Sollukattu) and (visual) sequence of postures (Adavu) of Bharatanatyam, we next capture the synchronization of the events. As the pos-
Table 11. Vocabulary of positions / formations of head (Shiro Bheda)

| • Samam  |
| • Adhomukham  |
| • Back Paravrittam  |
| • Udahatam  |
| • Ardha Aalolitam  |  

| • Left Adhomukham  |
| • Left Adhomukham  |
| • Left Paravrittam  |
| • Left Paravrittam  |
| • Left Utshiptam  |  

| • Right Adhomukham  |
| • Right Ardha Paravrittam  |
| • Right Paravrittam  |
| • Right Paravrittam  |
| • Right Utshiptam  |

Table 12. Vocabulary of formations of hands (Hasta Mudra)

| • Alapadma  |
| • Kartarimukha  |
| • Mushti  |
| • Suchi  |  

| • Avahitya  |
| • Katakamukha  |
| • Pataka  |
| • Sanchi  |
| • Tripataka  |  

- Dotted lines denote isInstanceOf between an instance and a class
- Dashed lines denote has a between two an instances

Fig. 8. Ontology of Key Postures

tures are driven by and are synchronized with the beats of the music, and as the performance repeats after a bar of the rhythm, we capture the ontology of synchronization between an Adavu and its Sollukattu as in Figure 9. Here specific instances of beats – Beat 1, Beat 2, ···, Beat n – form the sequence of beats in a Sollukattu. So we expresses that Beat 1 isFollowedBy Beat 2, Beat 2 isFollowedBy Beat 3, and so on. Finally, after Beat n, the bar repeats, and hence, Beat n isFollowedBy Beat 1. Similarly, instances of key postures – Posture 1, Posture 2, ···, Posture n – form the sequence of postures in an Adavu that also repeats. Being driven by music, every beat triggers the corresponding posture. In the figure, we show only one cycle (bar) of the Taalam. In an Adavu, usually 1,
2, 4, 6, 8, or more number of repetitions are performed by the dancer. Explicit instances of *bol* and time instants are omitted on the diagram for better clarity.

![Diagram of Adavus and postures in Bharatanatyam](image)

**Fig. 9.** Ontology of Audio-Visual Sync in *Bharatanatyam*

In this section, we have captured the central concepts of *Bharatanatyam* Adavus in terms of a set of object-based ontological models. These models identify the key items with their interrelationships and help the annotation of data sets for training as well as testing. Naturally, they lead to algorithms for the analysis and recognition of various items (like *bol* and postures). However, these models are structural, and hence, are limited in their temporal specification.

## 4 Event-based Modeling of Adavus

The framework used so far is good for taxonomical and partonomical representation but lacks the expressibility in temporal terms. But Dance is multimedia in nature with music driving the steps. In order to capture dynamic association between music and video, we first tried to use the concept of triggers to model synchronization of events. The progression of time is captured by simple sequences (*isFollowedBy*) of occurrences of *bol* and beats. This approach is illustrated in Figure 9. Since a simple sequence of *bol* and beats misses actual quantum of time slice, it cannot deal with triggers between beat and posture actions, and cannot ensure equal time gap between beats. Temporal behavioral models are necessary to analyze and recognize such temporal and synchronization details in depth. Hence, we introduce an event-based modeling framework...
that, on one hand, can relate to the key concepts as introduced above and is
defined in terms of temporal relationships on the other.

This event-based framework treats a performance as a multimedia stream
and takes the models closer to the structure of the data that we capture later
by Kinect. A Bharatanatyam Adavu, therefore, consists of (1) Composite Audio
Stream (Sollakattu) containing – (a) Instrumental Sub-stream as generated by
instrumental strikes and (b) Vocal Sub-stream as generated by vocalizations or
bolks; (2) Video Stream of frames containing either – (a) Key Posture (called, K-
Frame), or (b) Transition Posture (called, T-Frame); and (3) Synchronization
(Sync) of Position, Posture, Movement, and Gesture of an Adavu as performed
in synchronization among themselves, and in synchronization with the rhythm
of the music. In Instrumental and Vocal Sub-streams of a Sollukattu, beating and
bolks are usually generated in sync. The rules or structure of synchronization have
been defined for every Sollakattu in Bharatanatyam.

4.1 Events of Adavus

An Event denotes the occurrence of an activity (called Causal Activity) in the
audio or the video stream of an Adavu. Further, sync events are defined be-
tween multiple events based on temporal constraints. Sync events may be defined
jointly between audio and video streams. An event is described by:

1. **Category:** The nature of the event based on its origin (audio, video or sync).
2. **Type:** Type relates to the causal activity of an event in a given category.

   Event types are listed in Table [13] with brief description.
3. **Time-stamp / range:** The time of occurrence of the causal activity of the
   event. This is elapsed time from the beginning of the stream and is marked
   by a function \( \tau(.) \). Often a causal activity may spread over an interval \([\tau_s, \tau_e]\)
   which will be associated with the event. For video events, we use range of
   video frame numbers \([\eta_s, \eta_e]\) as the temporal interval. Since the video has a
   fixed rate of 30 fps, for any event we interchangeably use \([\tau_s, \tau_e]\) or \([\eta_s, \eta_e]\)
   as is appropriate in a context.
4. **Label:** Optional labels may be attached to an event for annotating details.
5. **ID:** Every instance of an event in a stream is distinguishable. These are
   sequentially numbered in the temporal order of their occurrence (Table [16]).

The list of events are given in Table [13] and characterized in the next sections.

4.2 Characterization of Audio Events

A Sollukattu is the musical meter of an Adavu. Traditionally, a Tatta Palahai
(wooden stick) is periodically struck on a Tatta Kozhi (wooden block) in the
rhythmic pattern of Adi or Roopakam Taalam to produce the periodic beats (or
\( \alpha^{\text{th}} \) events in Table [14]). Usually beats repeat in a bar\(^{13}\) of \( \Lambda = 6 \) or 8. The tempo

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\(^{13}\) A bar (or measure) is a segment of time corresponding to a specific \( \Lambda \) number of
beats. Sollukattus also use longer bars (12, 16, 24, or 32).
Table 13. List of Events of Adavus

| Event Category | Event Type | Event Description | Event Label |
|----------------|-----------|------------------|-------------|
| Audio          | α_{fb}    | Full beat with bol | bol, downbeat, upbeat |
| Audio          | α_{hb}    | Half beat with bol | bol         |
| Audio          | α_{qb}    | Quarter beat with bol | bol         |
| Audio          | α_{fn}    | Full beat having no upbeat | bol         |
| Audio          | β         | bol is vocalized | bol         |
| Video          | ν_{nm}    | No motion | Range of Frames, Key Posture |
| Video          | ν_{tr}    | Transition Motion | Range of Frames |
| Video          | ν_{tj}    | Trajectory Motion | Range of Frames, Trajectory |
| Sync           | φ_{fb}    | bol @ Full beat | bol         |
| Sync           | φ_{hb}    | bol @ Half beat | bol         |
| Sync           | ψ_{fb}    | No motion @ Full beat | Key Posture |
| Sync           | ψ_{hb}    | No motion @ Half beat | Key Posture |

1: A (full) beat is the basic unit of time – an instance on the timescale
2: Vocalized bol accompany some beats
3: The first beat of a bar
4: The last beat in the previous bar which immediately precedes the downbeat
5: Half beats are soft strikes at the middle of a tempo period
6: Quarter beats strike at the middle of a Full-to-Half or a Half-to-Full beat
7: Frames over which the dancer does not move (assumes a Key Posture)
8: Sequence of consecutive frames over which the events spreads
9: A Key Posture is a well-defined and stationery posture
10: Transitory motion to change from one Key Posture to the next
11: Motion that follows a well-defined trajectory of movement for limbs
12: α_{fb} and ν_{nm} in sync. That is, \( \tau(\alpha_{fb}) \cap \tau(\nu_{nm}) \neq \phi \)

of a meter is measured by beats per minute (bpm) and can be slow, medium or fast. We use Tempo Period or Period \( T = \frac{60}{\text{bpm}} \) or the time interval between two consecutive beats in secs as the temporal measure for a meter.

In the current work we use only the slow tempo. While there is no fixed definition for the bpm of a slow tempo (medium and fast progressively doubles relative to the slow one), it is typically found to be between 75 (period = 0.8 sec.) and 30 (period = 2 sec.) in most of the performances. Theoretically, the tempo period should not vary during the performance of a specific Sollukattu or across Sollukattus. However, in reality it does vary depending on the skill of the beat player. Naturally, the event model needs to take care of such variations.

Next let us consider two consecutive beats \( \alpha_{1}^{fb} \) and \( \alpha_{i+1}^{fb} \) in a bar of length \( A \), where \( i \) denotes the \( i^{th} \) (1 \( \leq i < A \)) period. The time-stamps of the respective events are then related as \( \tau(\alpha_{i+1}^{fb}) - \tau(\alpha_{i}^{fb}) \approx T \). Further the bar repeats after an equal time interval of \( T \). That is, \( \tau(\alpha_{A+i+1}^{fb}) - \tau(\alpha_{A+i}^{fb}) \approx T, i \geq 1 \). We refer to such beats as full beats and hence the superscript \( fb \) in \( \alpha_{i}^{fb} \) events. The first beat \( \alpha_{0}^{fb} \) (last beat \( \alpha_{A-1}^{fb} \)) of a bar is referred to as a downbeat (upbeat). We mark these on the events as labels. In many Sollukattus beating is also performed at the middle of a period. These are called half beats and produce the \( \alpha_{i}^{hb} \) events in the \( i^{th} \) period. Naturally, \( \tau(\alpha_{i+1}^{hb}) - \tau(\alpha_{i}^{hb}) \approx \tau(\alpha_{i+1}^{fb}) - \tau(\alpha_{i}^{hb}) \approx T/2 \).
Often in a *Sollukattu* the beat player (an accomplice of the dancer) also utters *bol*s. These are done in sync with a full beat or a half beat. We represent *bol*s as labels of the respective $\alpha^f$ or $\alpha^h$ events. A *bol* is *optional* for an event.

It may be noted that a beat is actually an instant of time that occurs in every $T$ secs. So it is possible that a beat has no beating (and obviously no *bol*). Such cases, however, are not in the scope of the present study and we always work with a beating at a beat.

There are 23 *Sollukattus*. We illustrate a few here to understand various meters. All *Sollukattus* are shown in slow tempo or *Vilambit Laya*.

1. **Kuditta Mettu** ($T \approx 1.2$ secs, $A = 8$): We show two bars in Tables 14 with *bol*s and time-stamps. In Figure 10 we illustrate the signal for a *Kuditta Mettu* recording highlighting various events, time-stamps, and *bol*s. While this *Sollukattu* has only $\alpha^f$ events by definition, some incidental $\alpha^h$ events can still be seen in the signal. These will need to be later removed. Table 16 shows its relationship with the *Adavu*.

| Event | Time (sec.) | Beat Offset | Event | Time (sec.) | Beat Offset |
|-------|-------------|-------------|-------|-------------|-------------|
| $\alpha^f$ (tei) | 2.681 | $\tau(\alpha_{i+1}) - \tau(\alpha_i)$ | $\alpha^f$ (tei) | 12.271 | 1.207 |
| $\alpha^f$ (hat) | 3.912 | 1.231 | $\alpha^f$ (hat) | 13.386 | 1.115 |
| $\alpha^f$ (tei) | 5.108 | 1.196 | $\alpha^f$ (tei) | 14.512 | 1.126 |
| $\alpha^f$ (hi) | 6.269 | 1.161 | $\alpha^f$ (hi) | 15.603 | 1.091 |
| $\alpha^f$ (tei) | 7.523 | 1.254 | $\alpha^f$ (tei) | 16.764 | 1.161 |
| $\alpha^f$ (hat) | 8.742 | 1.219 | $\alpha^f$ (hat) | 17.902 | 1.138 |
| $\alpha^f$ (tei) | 9.891 | 1.149 | $\alpha^f$ (tei) | 19.028 | 1.126 |
| $\alpha^f$ (hi) | 11.064 | 1.173 | $\alpha^f$ (hi) | 20.178 | 1.150 |

$T = 1.2$ sec., $A = 8$

2. **Tatta_C** ($T \approx 1.6$ secs, $A = 8$): It has $\alpha^f$ as well as $\alpha^h$ events (Table 15 and Figure 11).

3. **Kuditta Nattal_A & Tatta_E** ($T \approx 1.0$ secs, $A = 8$): In addition to $\alpha^f$, $\alpha^n$ and $\alpha^h$ events are also found (Table 16) where there is only beating and no *bol*.

4. **Joining_B** ($T \approx 1.5$ secs, $A = 8$): As such it uses only $\alpha^f$’s (Table 16).

All *Sollukattus* in terms of the *Bols* are listed in Table 1.

### 4.3 Characterization of Video Events

While performing an *Adavu* the dancer closely follows the beats of the accompanying music. At a beat, the dancer assumes a *Key Posture* and holds it for a little
**Parameters**: No. of bars = 2, \( A = 8 \) and \( T = 1.16 \) sec.

- Full beat (\( \alpha_{fb} \)) event positions are highlighted (yellow blobs) and corresponding \( boks \) and time-stamps are shown (Table 14). Note that several \( \alpha_{hn} \) are visible in the signals. These are rather incidental and not intended in the Sollukattu. Also, the beatings before the downbeat (\( \alpha_{l} \)) are ignored. Right-sided **Key Postures** (Figure 12) are also shown for the first 8 beats. Left-sided **Key Postures** are performed for the next 8 beats.

**Fig. 10.** Marking of beats and annotations of \( boks \) for Kuditta Mettu Sollukattu

while before quickly changing to the next **Key Posture** at the next beat. Consequently, while the dancer holds the key posture, she stays almost stationary and there is no or very slow motion in the video. This leads to \( \nu_{nm} \) no-motion events. Further, while the dancer changes to the next key posture, we observe the \( \nu_{tr} \) (transition) or \( \nu_{tj} \) (trajectory) motion events. Since a frame is an atomic observable unit in a video, we can classify the frames of the video of an Adavu into 2 classes:

1. **K-frames or Key Frames**: These frames contain key postures where the dancer *holds* the Posture. Evidently, a \( \nu_{nm} \) has the sequence of K-frames as labels. All K-frames of an \( \nu_{nm} \) contain the same key posture.

2. **T-frames of Transition Frame**: These are transition frames between two K-frames while the dancer is rapidly changing posture to assume the next key posture from the previous one. T-frames contain Natural Transition Postures (leading to \( \nu_{tr} \) events) or Trajectorial Transition Postures (leading to \( \nu_{tj} \) events). A \( \nu_{tr} \) or \( \nu_{tj} \) event has the corresponding sequence of T-frames as labels. In the current work, we do not deal with movements and transitions. Hence, we ignore T-frames.

In Figure 12 we show the key postures of Kuditta Mettu Adavu at every beat of the first bar of Kuditta Mettu Sollukattu. The corresponding video and audio
Table 15. Patterns of Tatta_C Sollukattu (Figure 10 (b))

| Event   | Time (sec.) | Beat Offset (sec.) | 1/2–Beat Offset (sec.) |
|---------|-------------|--------------------|------------------------|
|         | (τ(α))     | (τ(α_fb^i+1) − τ(α_fb^i)) | (τ(α_hb^i) − τ(α_fb^i)) |
| α_fb^1 (tei) | 6.571       |                     |                        |
| α fb^1 (ya)   | 7.395       |                     | 0.82                   |
| α_fb^2 (tei) | 8.185       | 1.61                |                        |
| α fb^2 (ya)   | 8.962       |                     | 0.78                   |
| α fb^3 (tei) | 9.752       | 1.57                |                        |
| α fb^3 (ya)   | 10.565      |                     | 0.81                   |
| α fb^4 (tei) | 11.366      | 1.61                |                        |
| α fb^4 (ya)   | 13.003      |                     | 1.64                   |
| α fb^5 (tei) | 13.815      |                     | 0.81                   |
| α fb^5 (ya)   | 14.628      | 1.63                |                        |
| α fb^6 (tei) | 15.441      |                     | 0.81                   |
| α fb^6 (ya)   | 16.184      | 1.56                |                        |
| α fb^7 (tei) | 17.031      |                     | 0.85                   |
| α fb^7 (ya)   | 17.809      | 1.63                |                        |

● $T = 1.6$ sec., $A = 8$

- Parameters: No. of bars = 2, $A = 8$ and $T = 1.56$ sec.
- Full beat ($α fb$) (yellow blobs) and half beat ($α hb$) (green blobs) event positions are highlighted and corresponding bols and time-stamps are shown (Table 15).

Fig. 11. Marking of beats and annotations of bols for Tatta_C Sollukattu

Events are marked in Table 17 with K-/T-Frames. These are also marked on the
Table 16. Variations in the patterns of Sollukattus with Adavus

| Sollukattu | Description of Bol / Adavus |
|------------|-----------------------------|
| **Kuditta** | $\alpha_1^b$ (tei) $\alpha_2^b$ (hat) $\alpha_3^b$ (tei) $\alpha_4^b$ (hi) |
| **Mettu**  | $\alpha_5^b$ (tei) $\alpha_6^b$ (hat) $\alpha_7^b$ (tei) $\alpha_8^b$ (hi) |
| **Adavu: Kuditta Mettu 1, 2, 3, 4** |

| **Kuditta** | $\alpha_1^b$ (tat) $\alpha_2^b$ (tei) $\alpha_3^n$ $\alpha_4^b$ (tam) $\alpha_4^n$ $\alpha_4^n$ |
| **Nattal A** | $\alpha_5^b$ (dhit) $\alpha_6^b$ (tei) $\alpha_6^n$ $\alpha_7^b$ (tam) $\alpha_8^n$ $\alpha_8^n$ |
| **Adavu: Kuditta Nattal 1, 2, 3, 6** |

| **Tatta E** | $\alpha_1^b$ (tei) $\alpha_2^b$ (tei) $\alpha_3^n$ $\alpha_4^n$ |
| **Adavu: Tatta 6** |

| **Joining B** | $\alpha_1^b$ (dhit) $\alpha_2^b$ (dhit) $\alpha_3^b$ (tei) |
| **Adavu: Joining 2** |

- Sollukattu = Kuditta Mettu with bols for Bar 1.
- From a tei to the next hat or hi the dancer sharply lowers her raised feet.
- Further, 8 left-sided Key Postures are performed for the next 8 beats in Bar 2.

Fig. 12. Right-sided Key Postures of Kuditta Mettu Adavu (Variant 2)

*Sollukattu* in Figure 10. Note that only the right-sided half of the postures are shown in both figures.
Table 17. Patterns of Kuditta Mettu Adavu (Figure 12)

| Events | K-/T-Frames | Events | K-/T-Frames |
|--------|-------------|--------|-------------|
| $\nu_1^{nm}$ [$\alpha_1^{fb}$ (tei)] | 70–99 | 30 | $\nu_5^{nm}$ [$\alpha_5^{fb}$ (tei)] | 359–386 | 28 |
| $\nu_2^{tr}$ | 100–103 | 4 | $\nu_1^{tr}$ | 411–429 | 19 |
| $\nu_2^{nm}$ [$\alpha_2^{fb}$ (hat)] | 104–124 | 21 | $\nu_0^{nm}$ [$\alpha_0^{fb}$ (hat)] | 391–410 | 20 |
| $\nu_2^{tr}$ | 125–145 | 21 | $\nu_0^{tr}$ | 452–455 | 4 |
| $\nu_3^{nm}$ [$\alpha_3^{fb}$ (tei)] | 146–172 | 27 | $\nu_1^{nm}$ [$\alpha_{11}^{fb}$ (tei)] | 430–451 | 22 |
| $\nu_3^{tr}$ | 173–176 | 4 | $\nu_1^{tr}$ | 452–455 | 4 |
| $\nu_4^{nm}$ [$\alpha_4^{fb}$ (hi)] | 177–191 | 15 | $\nu_{12}^{nm}$ [$\alpha_{12}^{fb}$ (hi)] | 456–470 | 15 |
| $\nu_4^{tr}$ | 192–214 | 23 | $\nu_{12}^{tr}$ | 471–492 | 22 |
| $\nu_5^{nm}$ [$\alpha_5^{fb}$ (tei)] | 215–245 | 31 | $\nu_{13}^{nm}$ [$\alpha_{13}^{fb}$ (tei)] | 493–521 | 29 |
| $\nu_5^{tr}$ | 246–249 | 4 | $\nu_{13}^{tr}$ | 522–525 | 4 |
| $\nu_6^{nm}$ [$\alpha_6^{fb}$ (hat)] | 250–262 | 13 | $\nu_{14}^{nm}$ [$\alpha_{14}^{fb}$ (hat)] | 526–542 | 17 |
| $\nu_6^{tr}$ | 263–287 | 25 | $\nu_{14}^{tr}$ | 543–564 | 22 |
| $\nu_7^{nm}$ [$\alpha_7^{fb}$ (tei)] | 288–314 | 27 | $\nu_{15}^{nm}$ [$\alpha_{15}^{fb}$ (tei)] | 565–587 | 23 |
| $\nu_7^{tr}$ | 315–317 | 3 | $\nu_{15}^{tr}$ | 588–590 | 3 |
| $\nu_8^{nm}$ [$\alpha_8^{fb}$ (hi)] | 318–345 | 28 | $\nu_{16}^{nm}$ [$\alpha_{16}^{fb}$ (hi)] | 591–620 | 30 |
| $\nu_8^{tr}$ | 346–358 | 13 | $\nu_{16}^{tr}$ | 621–621 | 4 |

4.4 Characterization of Synchronization

A Bharatanatyam dancer intends to perform the key postures of an Adavu in synchronization with the beats. Hence various audio events like $\alpha^{fb}$ and corresponding video events like $\nu^{nm}$ should be in sync. Every Adavu has a well-defined set of rules that specifies this synchronization based on its associated Sollukattu. For example, in Figure 12 we show how different key postures of Kuditta Mettu Adavu should be assumed at every beat of the Kuditta Mettu Sollukattu. That is, how the $\alpha^{fb}$s of a bar in the audio should sync with the $\nu^{nm}$s of the video. Other Adavus require several other forms of synchronization between the audio-video events including sync between beats and trajectory-based body movements $\nu^{tj}$.

We assert a sync event $\psi^{fb}$ if a key posture ($\nu^{nm}$) should sync with a corresponding (full) beat ($\alpha^{fb}$). In simple terms, a $\psi^{fb}$ occurs if the time intervals of $\alpha^{fb}$ and $\nu^{nm}$ events overlap. That is, $\tau(\alpha^{fb}) \cap \tau(\nu^{nm}) \neq \phi$. Similar sync events may be defined between other audio and video events according to the rules of Adavus.
Perfect synchronization is always intended and desirable for a performance. However, we often observe the lack of it due to various reasons. The beating instrument, vocal *bol*, and body postures each has a different latency. If a posture is assumed after hearing the beat, $ν^{nm}$ will lag $α^{fb}$. If the dancer assumes the posture in *anticipation*, $ν^{nm}$ may lead $α^{fb}$. Lack of sync may also arise due to imperfect performance of the dancer, the beater or the vocalist. Hence, analysis and estimation of sync is critical for processing *Adavu*.

While sync between the audio and video streams is fundamental to the choreography, there are a variety of other synchronization issues that need to be explored. These include sync between beating (instrumental) beats and (vocalized) *bol*, uniformity of time gap between consecutive beats, sync between different body limbs while changing from one key posture to the next, and so on.

5 Ontology of Events and Streams

We have captured the structural models of *Sollukattus* and *Adavus* in Section 3 and then, the temporal behavioral models in Section 4 based on these structures. Now, we would like to relate these to the actual recording data of the performances. For the current work we capture the performances of Bharatanatyam *Adavus* using Kinect XBox 360 (Kinect 1.0) sensor. So in this section, we model the relationships between the events and the Kinect streams to facilitate the formulation of the algorithms later.

Kinect 1.0 is an RGBD sensor that captures a multi-channel audio stream with 3 video streams – RGB, Depth, and Skeleton in its data file. The video streams are captured at 30 frames per second (fps). The RGB stream comprises frames containing color intensity images. The depth stream comprises frames containing depth images. And the skeleton stream comprises frames containing 20-joints skeleton images of human beings in the view. The video streams are synchronized between themselves. Hence for any RGB frame, the corresponding depth and skeleton frames carry the same frame number. The audio is also synchronized with the video by the same clock. Hence, any time $t$ on the audio stream corresponds to an RGB (depth, skeleton) frame by $t/30$.

We now present a combined ontology for the events (as introduced in the last section) and the streams (of a Kinect data file), and capture their interrelationships. For this we identify sets of classes (Table 18), instances (Table 19), and relations (Table 20).

The ontology is presented in Figure 15. The following points about the ontology may be noted:

- The event-side is shown in blue and the stream-side is shown in black.
- A *K-frame* is a semantic notion that is instantiated as a triplet of an RGB, Depth and Skeleton frames. Also, it actually represents a sequence of consecutive frames in the video having *no-motion*. *T-frames* are treated similarly.
- *isExtractedFrom* represents the processes of extraction (or detection, estimation etc.) of audio (video) events from audio (video) streams. These are not
Table 18. List of Classes for the ontology of Events and Streams

| Class                        | Type   | Class                        | Type   |
|------------------------------|--------|------------------------------|--------|
| Kinect Data File             | Concrete | Audio-Event Stream           | Concrete |
| Audio Stream                 | Concrete | Video-Event Stream           | Concrete |
| Video Stream                 | Concrete | Audio Event                  | Abstract|
| RGB Stream                   | Concrete | Video Event                  | Abstract|
| Depth Stream                 | Concrete | Beat Event                   | Abstract|
| Skeleton Stream              | Concrete | Bol Event                    | Concrete|
| RGB Frame                    | Concrete | Full Beat Event              | Concrete|
| Depth Frame                  | Concrete | Half Beat Event              | Concrete|
| Skeleton Frame               | Concrete | Full Beat with bol (FB+B) Event | Concrete |
| K-Frame                      | Concrete | Half Beat with bol (HB+B) Event | Concrete |
| T-Frame                      | Concrete | No-Motion Event              | Concrete|
| :D.p, D, · · ·               |         | Skeleton Frame               | Concrete|
| :S.p, S, · · ·               |         | Transition Event             | Concrete|

Table 19. List of Instances for the ontology of Events and Streams

| Class:Instance                        | Remarks                                      |
|---------------------------------------|----------------------------------------------|
| Full Beat Event: FBB1, FBB2, · · ·     | Instances of full beat with bol events       |
| Half Beat Event: HBB1, HBB2, · · ·      | Instances of half beat with bol events       |
| No-Motion Event: NM1, NM2, · · ·        | Instances of no motion events                |
| K-Frame: I.p, I · · ·, I.p + u, · · ·   | Intensity (RGB) image frames from no. p to p + u |
| T-Frame: I.q + 1, I · · ·, I.q + v, · · · | Intensity image frames from no. q + 1 to q + v, where q = p + u |
| :D.p, D, · · ·                        | Depth image frames from number p             |
| :S.p, S, · · ·                        | Skeleton image frames from number p          |

Table 20. List of Relations for the ontology of Events and Streams

| Relation            | Domain          | Co-Domain        | Remarks                                                                 |
|---------------------|-----------------|------------------|-------------------------------------------------------------------------|
| is_a                | Class           | Class            | As in Table 7                                                           |
| has_a               | Class           | Class            | As in Table 7                                                           |
| isInstanceOf        | Instance        | Class            | As in Table 7                                                           |
| isSyncedWith        | Instance        | Instance         | Expresses low-level synchronization – between audio / video events and video frames. For example, an audio event FBB1 (instance of 'full-beat with bol') isSyncedWith a unique K-Frame. |
| isSequenceOf        | Class           | Class            | As in Table 7                                                           |
| isExtractedFrom     | Class           | Class            | An event isExtractedFrom Kinect video                                    |
| isInSync            | Relation over 3 Instances | Class          | Expresses the inherent synchronization in data – between audio and multiple video streams – RGB, Depth and Skeleton. Every RGB Frame isInSync with a corresponding Depth Frame or Skeleton Frame. |

All relations, with the exception of 'isInSync', are binary

Directly available from the Kinect streams and need to be computationally determined. Specific algorithms required include:

- Beat detection to produce $\alpha_f$ or $\alpha_h$
- Bol recognition to produce $\alpha_f^b(<bol>)$ or $\alpha_h^b(<bol>)$
- No-Motion detection to produce $\nu^{nm}$ events

- isInSync represents the fact that streams in Kinect are synchronized by the sensor.
- In contrast isSyncedWith denotes the explicit attempt of the dancer to synchronize her / his moves and postures with the beats and bols. These are
ψ_{fb} or ψ_{hb} events. To estimate isSyncedWith, K-Frames and T-frames need to be extracted.

Fig. 13. Ontology of Kinect Data File, Streams and Audio-Video Events

6 Representation of Adavus in Labanotation

We intend to represent Bharatantyam ontology according to the ontology of a parse-able standard notation. Labanotation [3] (often referred to as Laban Encoding or simply Laban) is a standard notation system used for recording human movements. To record a movement the Laban system symbolizes space, time, energy, and body parts. Here, we introduce a limited set of symbols that are particularly used for representing posture of Bharatantyam Adavus. A Posture are encoded in laban is called frame and the laban frames are stack in laban staff as shown in Figure 14. When there is a sequence of postures or gestures changing over time, we stack their symbols on the staff vertically to show the progression over time. The center line of the staff indicates the time. The symbols are read from the bottom to the top of the staff.

The Staff represents the body. The Center Line divides the body into two parts – Left and Right. The immediate next to the center line are Support Columns. The symbols placed in these columns indicate the body parts which carry the weight of the body. Other columns are represent the gestures of other body parts such as Leg, Body (torso), Arm, and Head. Except head, other body parts have left and right columns. Labanotation captures the movements of the human body parts in terms of the directions and levels of the movement. The
direction symbols are used to indicate in which direction in the space the movements occur and in any direction can have three different levels, namely, upward or high, horizontal or middle, and downwards or low. Every body part can be expressed in terms of the direction and level by placing respective symbols in the designated columns.
The arms and the legs do not always remain straight while performing an Adavu. Few joints of the body like knee and elbow can get folded. Hence degree of folding is useful for these joints. There are a total of six degrees of folding. Bharatanatyam also involves a lot of foot work. Hence, we need to encode the type of touch between the foot and the ground and also which part of the foot is in contact with the ground. Labanotation system has symbols to diagrammatically illustrate the specific part of the foot that contact the ground. This attribute is called touch in Labanotation. There are 11 parts of foot that can touch the ground. The concepts are shown in Figure 16.

We want to use concepts of Labanotation to transcript the data captured by the sensor into machine parse-able form. We map the kinect data to the concepts Bharatanatyam in Figure 15. Now, we intend to map the concept of Bharatanatyam to the concept of Labanotation as our goal is generate a parse-able XML descriptor of Bharatanatyam Adavu. The ontology is shown in Figure 17. There are 4 layers in the ontology:

1. **Input or Sensor Layer**: This layers contains the data captured by the sensor. We capture the video of the dance using Kinect sensor. The data contains the K-frames as well as T-frames. Here we intend to transcript only the K-frames.

2. **Dance Layer**: According to the ontology shown in Figure 15 the K-frames contains No-Motions events. The No-Motions events are nothing but the Key postures of Bharatanatyam Adavu as shown in Figure 8. Here, we map the key posture in terms of direction, level, degree of folding and touch concept of Labanotation. The leg, arm and head of a key posture are get mapped into the Laban concept.

3. **Laban Descriptor Layer**: Each key posture has corresponding Laban frame in the Laban staff. The legs described in terms of leg and support of Labanotation. Arm and head have one to one mapping between Bharatanatyam ontology to Laban ontology.

![Fig. 16. Ontology of Labanotation](image)
4. **Transcript Layer**: Finally, the Laban ontology gets encoded into a parseable XML format so that the Labanotation can get visualized or animation can get generated from the XML.

7 **Laban Encoding of an Adavu Posture**

We represent Adavu as a sequence of key postures. To transcribe an Adavu, we need to transcribe every key posture that occur in the Adavu. For the purpose of use, we encode the symbols of direction and level in Table 21, the degree of folding in Table 22, and the touch attribute in Table 23.

| Direction | Place | Left Side | Right Side | Left Forward | Right Forward | Left Backward |
|-----------|-------|-----------|------------|--------------|---------------|---------------|
| Encoding  | 1     | 2         | 3          | 4            | 5             | 6             |

| Direction | Right Backward | Right Forward Diagonal | Left Backward | Right Forward | Left Forward | Right Forward Diagonal |
|-----------|----------------|------------------------|---------------|--------------|--------------|------------------------|
| Encoding  | 1              | 2                      | 3             | 4            | 5            | 6                      |

| Level | HIGH | MID | LOW |
|-------|------|-----|-----|
| Encoding | 1   | 2   | 3   |
Table 22. Degree of Folding

| Degree of Folding | No Fold | Fold Degree 1 | Fold Degree 2 | Fold Degree 3 | Fold Degree 4 | Fold Degree 5 | Full Fold |
|-------------------|---------|---------------|---------------|---------------|---------------|---------------|-----------|
| Encoding          | 0       | 1             | 2             | 3             | 4             | 5             | 6         |

Table 23. Type of touch with floor

| Foot Parts | Full heel | One half heel | Whole foot | One eighth ball | One fourth ball | One half ball |
|------------|-----------|---------------|------------|-----------------|-----------------|---------------|
| Encoding   | 1         | 2             | 3          | 4               | 5               | 6             |

| Foot Parts | Full ball | Pad of toe | Full toe | Nail of toe | No touch |
|------------|-----------|------------|----------|-------------|----------|
| Encoding   | 7         | 9          | 9        | 10          | 0        |

Table 24. Annotation of the video of Natta Adavu Variation 1

| Posture Name (a) | Start Frame (b) | End Frame (c) | Beat Number (d) | Bols |
|------------------|-----------------|---------------|-----------------|------|
| Natta1P1         | 70              | 80            | 0               | No Bol |
| Natta1P2         | 101             | 134           | 1               | tei yum |
| Natta1P1         | 144             | 174           | 2               | tat ta |
| Natta1P3         | 189             | 218           | 3               | tei yum |
| Natta1P1         | 231             | 261           | 4               | ta      |

The sequence of key postures occurring in the first 4 beats of Natta Adavu Variation 1 are shown in Table 24. A posture is described in terms of legs, arms, head, and hands using the vocabulary (Section 3.3) for the annotation of the limbs. Now, we want to transcribe the posture. Hence, we need to encode the body parts from Bharatanatyam terminology to Labanotation descriptor. For example, consider key posture Natta1P1 Natta Adavu Variation 1. Let us describe the posture using the Labanotation symbols. The posture is shown in Figure 19. The different body parts of the posture are marked in different colors like arm is marked as yellow. Annotation of the body parts of postures Natta1P1 is given in Table 25 (We exclude Hasta Mudra from the transcription work).

Table 25. Annotation of the body parts of postures in Natta Adavu 1

| Body Part | Position   | Formation | Vocab |
|-----------|------------|-----------|-------|
| Leg       | Aayata $[S]$ | Aayata   | Aayata | Table 9 |
| Arm       | Natyarambhe $[S]$ | Natyarambhe | Natyarambhe | Table 10 |
| Head      | Samam      |           |       | Table 11 |
The next challenge is to map the *Bharatanatyam* ontology to the Labanotation ontology. As an example, we encode the posture Natta1P1 (Figure 18, Table 25) to Laban in Table 26 and Figure 19.

1. **Leg**: The leg is in *Aayata* position which means:
   - The weight of the body is on both legs. So the legs are in support (as both leg are taking the weight of the body). The Support Direction and Support Level are encoded accordingly in Table 26.
   - The left (right) foot is in left (right) direction. The legs are not stretched in any direction, so the legs are in place.
   - The folding of the legs indicate that the level of the leg is low.
   - The legs are not crossing each other, so the Leg Crossing = 0.
   - We mark the symmetric position of both the legs using Mirror = 1. If Mirror = 1, then the direction of the right leg will just be in the opposite of the left leg.
   - The body weight is not on hip so Hip Support = 0.
   - Both legs are folded at the knee. The Knee in folding in around 90°, so Knee Folding = 3 (Figure 22).
   - The whole feet are touching the ground, so Touch = 3 (Figure 23).

2. **Arm**: The arms are in *Natyarambhe* which means:
   - The hands are stretched in left and right side of the body at the shoulder level and are slightly folded at elbow. So, Arm Direction = 2, Arm Level = 2 and Elbow Folding = 1.
   - Arm is not occluding with the body (Body Inclusion = 0) and
   - Both arms are similar (Mirror = 1).

3. **Head**: The head is in *Samam* which means:
   - The head is straight and forward (Head Direction = 1 and Level = Middle).
The complete Laban encoding for Natta1P1 is shown in Table 26. In a similar manner we have encoded the other postures used in Bharatanatyam Adavu. This has been done with the help of the experts.

### Table 26. Laban Encoding of Leg, Arm and Head of Posture = Natta1P1

| Leg Vocab | Support Direction | Support Level | Leg Direction | Leg Level | Leg Crossing | Mirror |
|-----------|-------------------|--------------|---------------|-----------|--------------|--------|
| Aayata    | 1                 | 3            | 0             | 0         | 0            | 1      |
|           | Hip Support       | 0            | Knee Folding  | 3         | Touch        |        |

| Arm Vocab | Arm Direction | Arm Level | Arm Crossing | Elbow Folding | Body Inclusion | Mirror |
|-----------|---------------|-----------|--------------|---------------|----------------|--------|
| Natyaramble | 2             | 2         | 0            | 1             | 0              | 1      |

| Head Vocab | Direction | Level |
|------------|-----------|-------|
| Samam      | 1         | 2     |

![Labanotation of Leg, Arm and Head of Posture = Natta1P1](image)

Fig. 19. Labanotation of Leg, Arm and Head of Posture = Natta1P1

### 7.1 LabanXML

While the graphical symbolization of Laban and our encoding in tabular formats as above are both forms of transcription, neither is amenable to machine processing. To visualize the postures and to build further applications based on the transcripts, we need a searchable and parseable representation. So we adopt LabanXML [8] – an *eXtensible Markup Language* (XML) design for Labanotation.
LabanXML bundles columns of the staff in four groups – left, right, support and head. Left and right, in turn, contains arm and leg.

The tags of LabanXML are as follows:

- `<laban>`: This is the root tag which includes `<attribute>` and `<notation>` tags.
- `<attribute>`: This includes tag `<title>` used to name the XML file.
- `<notation>`: This includes tag `<measure>`.
- `<measure>`: Which gives position of current pose on time line.
- `<left>`: Contains tags for columns appearing on left side of Labanotation.
- `<right>`: Contains tags for columns appearing on right side of Labanotation.
- `<support>`: Describes the support element in Labanotation columns. It has attribute `side` having value `left` or `right` indicating the side of the support.
- `<arm>`, `<leg>`, `<foot>`, `<head>`, and `<support>`: These tags include `<direction>` and `<level>` tags of the respective limb.
- `<elbow>`, `<knee>`: These tags include `<degree>` for degree of folding.
- `<touch>`: This tag is included in `<support>` tag and `<leg>` tag. It describes how foot is hooked to floor.

Using the above tags, we represent the information from Table 26 in XML format in Table 27. The graphical representation of Laban encoding is shown in Figure 19. The symbols described earlier are used to write the XML tags in Laban staff.

**Table 27. LabanXML of Posture Natta1P1**
7.2 Tool Overview

To build the *Adavu* Transcription Tool, we first encode our ontological models of *Adavu*, especially the key postures and their sequences, and the video annotations in Laban ontology following the approach as illustrated in Section 7. This cross-ontology of concepts (called *Posture Ontology*) are then represented in a mapping database indexed by the posture ID. This is used by the *Adavu* Transcription Tool as given in Figure 20. We explain the modules below.

**Fig. 20.** Architecture of the *Adavu* Transcription Tool

**Posture Recognizer** This is a machine learning based system [6] helps to recognize a unique posture id when RGB frame of key posture is given. We first extract the human figure, eliminate the background, and convert the RGB into grayscale image. We next compute the **Histograms of Oriented Gradient** (HOG) descriptors for each posture frame. Finally, we use HOG feature to train the same SVM classifier. There are total 23 key postures in *Natta Adavu*. To recognize the postures into 23 posture classes, we use **One vs. Rest** type of multi-class SVM. The data set shown in Table 28 is used for training and testing the SVM. For testing we use the trained SVM models to predict the class labels. Our accuracy of the posture recognition is 97.95%.

Now we use the trained classifier to recognize the input sequence of key postures. The key posture recognizer extract the sequence of key postures in terms of their posture IDs from the video of an *Adavu* performance.

**Indexing Laban Descriptor by Posture ID** Given a posture ID, we look up the *Posture Ontology* to get the Laban descriptor values for the different limbs in terms of a database record.
LabanXML Generator  From the database record of Laban descriptors an equivalent LabanXML file is generated using the definition of tags as in Section 7.1

Laban Visualizer  Since Labanotation is graphical, it is important to visualize it in terms of its icons. So we implement a converter from LabanXML to Scalable Vector Graphics (SVG). SVG is an XML-based vector image format for two-dimensional graphics with support for interactivity and animation. Like XML, SVG images can also be created and edited with any text editor, as well as with drawing software. The SVG converter is written in C++ on cygwin64 using
Table 28. Data Set for Posture Recognition using 23 posture classes in Figure 21

| Posture ID | Training data | Test data | Posture ID | Training data | Test data |
|------------|---------------|-----------|------------|---------------|-----------|
| C01        | 6154          | 1457      | C13        | 235           | 80        |
| C02        | 3337          | 873       | C14        | 393           | 117       |
| C03        | 3279          | 561       | C15        | 404           | 121       |
| C04        | 1214          | 219       | C16        | 150           | 48        |
| C05        | 1192          | 268       | C17        | 161           | 51        |
| C06        | 1419          | 541       | C18        | 323           | 81        |
| C07        | 1250          | 475       | C19        | 175           | 46        |
| C08        | 284           | 112       | C20        | 168           | 43        |
| C09        | 306           | 133       | C21        | 19            | 6         |
| C10        | 397           | 162       | C22        | 21            | 6         |
| C11        | 408           | 117       | C23        | 118           | 61        |
| C12        | 229           | 84        |            |               |           |

Numbers indicate the number of $K$-frames. Each $K$-frame is given by the frame number of the RGB frame in the video. Associated depth and skeleton frames are used as needed. Various position and formation information on body parts are available for every $K$-frame from annotation.

Fig. 22. Key postures of Natta Adavu Variant 1 with transcription in LabanXML (a part) and depiction in Laban Staff by our tool
7.3 Results and Discussion

Our tool is able to generate transcription for a sequence of key frames. For given a sequence of RGB frames, Posture Recognizer generates their posture IDs. These posture IDs are mapped to corresponding cluster IDs in the laban ontology. By using posture IDs and ontology a Laban transcription for all frames is encoded in LabanXML. By using LabanXML a stack of Labans for BN Adavu key postures is generated. The Laban XML and stack of postures in Laban Staff, as generated by our tool for the sequence of key postures of Natta Adavu variation 1, are shown in Figure 22. For a sequence of key frames from Natta Adavu 1, we show the transcription in Figure 22. The RGB frames are shown on left and the corresponding Laban descriptors are shown on the staff on right. An initial part of the LabanXML is given in the middle.

8 Conclusion

In this paper, we demonstrate a system to generate parse-able representation of Bharatanatyam dance performance and document the parse-able representation using Labanotation. The system uses a unique combination of multimedia ontology and machine learning techniques. To the best of our knowledge this is the first work towards automatic documentation of dance using any notation.

In the process of developing the system, we have also presented a detailed ontology for Bharatanatyam Adavus which is a maiden such attempt for any Indian Classical Dance. Finally, we have captured and annotated a sizable dataset for Adavus, part of which is also available for use at: [5].

In future we intend to extend our work to document more fine description of each postures. We are also interested to capture movement which we have used for this study. Finally, we also want to extend our work to generate the ontology automatically guided by the grammar of the dance form.

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