A knowledge-based approach to computational analysis of melody in Indian art music

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Abstract. Knowledge representation technologies developed in the semantic web context can be utilized to bridge the gap between music information research and disciplines like musicology and music theory. This will greatly enhance the impact they have on each other. Further, it will facilitate a knowledge-guided comparison and integration of different models of the same musical concept. But the current development state of ontologies for music is limited in its scope to address these issues. There is a need to develop ontologies for concepts and relationships coming from music theory. In this article, we discuss the melodic concepts that constitute the rāga, the melodic framework of Indian art music, specifically in the context of creating ontologies. We present a first version of the rāga ontology, and discuss the challenges posed by modeling semantics of its substructures.

1 Introduction

There is a growing interest within music information research community towards developing culture-specific approaches [1, 2, 3]. In order to better understand the interpretation of concepts involved in computational modeling, researchers collaborate with musicologist and musician experts in the music being studied. The conceptual description of music, arising out of such ad-hoc collaborations, by itself is not usually the end goal of information researchers. It forms a means to build the model, but does not become a part of it. Consequently it is lost, making it difficult to be reproducible/accessible for reuse by other researchers. It limits the comprehensibility of the model, and poses difficult challenges to compare or integrate different models of the concept.

Ontologies have been successfully used to address similar problems in other domains, like bioinformatics [4]. Within the information research community, an ontology is broadly understood to be a formal specification of a shared conceptualization [5]. Besides addressing the problems stated, ontologies, in the context of semantic web [6], serve a host of purposes relevant to information retrieval. Advances in the development of efficient inference procedures for highly expressive description logics, have enabled them to provide a suitable logical formalism to ontology languages [7]. This enables ontologies to be knowledge-bases, which combined with reasoning engines can be integrated into information systems. Further, an ontology specification allows the agents on semantic web to communicate with each other using common terminology and semantics, allowing a knowledge-guided comparison and integration of models developed for the same concept. Furthermore, this in turn opens avenues to a multitude of machine-intelligent applications [6].

The data in its present form on the web is structured for human consumption. Semantic web emphasizes the machine interpretability of the data published on web, and its interoperability between applications. Resource Description Framework (RDF)[1] is a standard model to represent the data on the web towards this extent. It facilitates evolution of data schemas without impeding the interaction between applications. MusicBrainz[2], an online public music metadata cataloging service, is one such example. It publishes the editorial metadata about various entities of an audio recording together with relationships between those entities, as XML serialized RDF. Client applications such as MusicBrainz Tagger and MusicBrainz Picard use this medium to communicate with the data server. RDF facilitates easy merger of data from different sources, for example, from MusicBrainz and DBpedia[3], as it dereferences each entity using Unique Resource Identifier (URI) on the web.

RDF Schema[4] provides constructors that allow us to define a set of classes and properties, more generally the vocabulary, appropriate to the application/purpose, using RDF. As an example, we can define a class called *Artist* and make statements about it (like, all *Artist*s are *Person*s, where Person is another class). This allows to create class and property hierarchies. Web Ontology Language (OWL)[5] is a class of semantic markup languages, which is mapped onto description logics of varying expressiveness. It builds on top of RDF and RDF Schema, and includes more expressive constructors such as universal and existential quantifiers, and cardinality constraints. These technologies and standards allow sharing complex knowledge about a domain with a lot of flexibility in their form, yet facilitating interoperability.

Consequently, there has been a surge in interest in ontologies in the information research community [8] (ch. 1). Within the domain of music information research, ontologies that concern different aspects of music, like production, cataloging, consumption and analysis have been developed: some of them are specific to applications in which the developer intends to use the ontology (Eg: Playback Ontology[6]), and some others are more general in their scope (Eg: Timeline[7] and Event[8] ontologies). The Music Ontology [9] builds on top of several ontologies - Timeline, Event, Functional Requirements and Bibliographic Records (FRBR)[9] and Friend Of A Friend (FOAF)[10] ontologies, defining music specific vocabulary. It caters to several needs such as expressing music creation workflows, temporal events and editorial metadata. LinkedBrainz[11] maps

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1 http://www.w3.org/RDF/
2 http://musicbrainz.org/
3 http://dbpedia.org/
4 http://www.w3.org/TR/rdf-schema/
5 http://www.w3.org/TR/owl-ref/
6 http://smiy.sourceforge.net/pbo/spec/playbackontology.html
7 http://purl.org/NET/c4dm/timeline.owl
8 http://purl.org/NET/c4dm/event.owl
9 http://vocab.org/frbr/core
10 http://xmlns.com/foaf/spec/
11 http://linkedbrainz.c4dmpresents.org/

different entities from MusicBrainz to corresponding concepts in Music Ontology, in an effort to publish MusicBrainz data as linked data [10].

However, there is a lack of ontologies for musical concepts taking their cultural context into consideration. In this article, we present the case for knowledge representation of concepts in Indian art music traditions. In sec. 2, we introduce Indian art music, and discuss the melodic aspects that constitute rāga, the melodic framework. We confine our scope to the concepts relevant to current practice, and as formalized in musicology. In sec. 3, we present a first version of the rāga ontology and discuss the challenges faced in modeling its substructures. In sec. 4, we briefly discuss the intended applications of the ontology in computational audio analysis and navigation of Indian art music collections.

2 Melodic framework in Indian art music

In the Indian subcontinent, there are two prominent art music traditions: Carnatic music in south India, and Hindustani music in north India, Pakistan and Bangladesh. Both of them are actively practiced and have a very relevant place in the current societal and cultural context. There is an abundance of historical and contemporary musicological texts [11, 12, 13, 14, 15, 16, 17, 18]. Apart from being testimonials to a rich activity, the annual events and festivals are venues to mark evolution of various concepts of the music through the interaction of musicians and scholars[12].

In the CompMusic project [1], we analyze melodic and rhythmic aspects of this music taking advantage of the domain knowledge obtained from musicological texts and from experts. We have also put a major effort in organizing the audio music collections with as much metadata and contextual information as possible [19]. In order to make a viable knowledge-base out of it, and facilitate public access to these resources, we embarked on the idea of publishing the gathered information as linked data in association with MusicBrainz. Both these goals necessitate building ontologies of the relevant musical concepts. In this section, we describe the melodic aspects of this music with an emphasis on using this as our starting point for building the needed ontologies. Though Carnatic and Hindustani music share musical concepts at a higher level, there are considerable differences [20]. In this article, we use the concepts and terminology of Carnatic music to present our case.

Rāga is the melodic framework of Indian art music. The core concepts which make up rāga are svaras, gamakas and phrases [21]. Svaras are seven in number per octave, with each of them in turn having variants at different pitch positions, except the tonic and the fifth which are considered as acala/immovable svaras. The variants are termed svarastānas and are twelve in number along with the tonic and the fifth (see Table 1 in [21]). For the sake of understanding, they can be thought of as being analogous to musical notes, but differing greatly in their semantics. Each svarastāna has a specific role to play in the phrases of the rāga: as a starting, ending or a rest position in a phrase, to mention a few. The melodic phrases are replete with gamakas, which are well-defined and formalized melodic movements. They form the ether for the movements

[12] Margazhi festival, also known as Madras Music Season is the most popular of them which brings together all the musicians and scholars annually: http://en.wikipedia.org/wiki/Madras_Music_Season

about and across the svarastānas. The extent of these movements over a svarastāna depends on its context as defined by its role in the rāga and its relation to other svarastānas (see [21] for a more complete description). This further impacts the intonation of the svarastāna [22, 23]. It means that the pitch position/temperament alone can not define a svarastāna completely. Indeed, the tuning analysis by J. Serrà *et al* [24] points out that Carnatic music, while showing a strong correlation with 5-limit just-intonation, is not strictly confined to the corresponding intervals. The same work argues that Hindustani music has a mix of intervals from 5-limit just intonation and equal tempered tuning. Both the observations can be explained by the additional semantics of a svarastāna.

A rāga is often depicted with an ascending and a descending progressions of svarastānas. In particular, it derives its identity from a specific phraseology with a selection of svarastānas. The melodic progressions, phraseology and functional roles of svarastānas in a rāga result in its telling character. Building an ontology for such an intricate melodic framework would allow us to understand the challenges concerning modeling of melodies in general.

Based on a number of characteristics and the intended purpose, there exist several classification schemes of rāgas. A popular scheme that is encountered frequently in musicological texts is the Mēḷakarta system[13] [18]. With a process called mēḷa prastāra[14], all the allowed combinations and permutations of svarastānas for seven positions are shown to result in 72 rāgas. These are divided into 12 subgroups each with 6 rāgas, based on the svarastānas chosen for seven positions. Rāgas with less than seven positions in either of their progressions are classified as child rāgas of one or more of these 72 mēḷakarta rāgas.

The Mēḷakarta system is said to be of interest primarily for scholars and musicologists, but not so much for music practitioners. There are other classifications based on the inherent musical properties of rāgas. We mention a few of them here and refer the readers to extensive musicological texts for more complete list of classifications [13, 14]. The vakra/krama classification of rāgas is based on the order of svaras in the ascending and descending progressions of the rāga. If there is a deviation such as a zig-zag pattern in either of these progressions, the rāga is said to be a vakra rāga. Otherwise, it is a krama rāga. The varjya/sampūrṇa classification of rāgas is based on the number of unique svaras in each of the progressions. There can be one, two or three omissions from among the seven positions in a progression. Based on the number of such omissions, the progression is said to be ṣāḍava, auḍava and svarāntara progression. Different combinations of such ascending and descending progressions give rise to different classes of rāgas. The upānga/bhāṣānga classification of rāgas says whether a child rāga makes use of only the svarastānas of its parent rāga as defined in mēḷakarta system (upānga) or otherwise (bhāṣānga).

3 Knowledge representation for the description of melodies

In this section, we present a first version of the ontology we are developing for the rāga structure discussed in the former section. An ontology of any concept depends

[13] http://en.wikipedia.org/wiki/Melakarta

[14] *Prastāra* in Sanskrit, means enumerating different combinations.

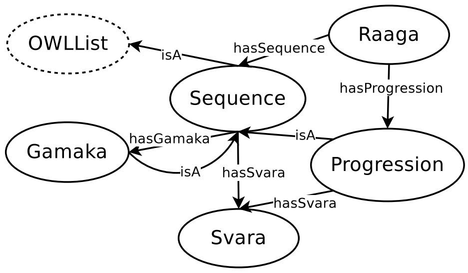

Fig. 1. The hierarchy and relationship between the top-level classes in the rāga ontology.

on its purpose and the perspective of knowledge engineer/ontologist, concerning political, cultural, social and philosophical aspects [25]. An ontology for rāga can stem from different points of view - it's historical evolution, teaching methodologies, role in the society, taxonomies etc. Our choice of design is influenced primarily by its intended use in melodic analysis and data navigation.

The top-level classes identified for the rāga ontology are svara, melodic sequence (hereby referred to as just sequence) and rāga. Fig. 1 shows the class relationships between these top-level entities. These relationships closely follow the rāga description in sec. 2. The svara forms the most atomic concept in the structures that make up a rāga. A subset of the svaras are arranged in an ascending/descending progressions. A rāga is represented by one ascending and one descending progression. It also has several characteristic melodic phrases that confine to the characteristics of the rāga. Such phrases are also combinations of svaras. For each of these top-level classes, we present the sub-class structure and their properties in the following subsections, also discussing the relevant example use-cases for such representation.

3.1 Svaras

Each svara has up to three variants, and in any given rāga only one variant is allowed. This rule extends to a few variants across svaras as well. Further, each of a few svarastānas must always be preceeded/succeeded by a specific svarastāna (see [21] for details). Fig. 2 shows part of the svara ontology with all the svaras, few variants and the relationships between them.

3.2 Sequences

The constructors available in OWL do not allow modeling ordered sequences [26]. The available alternatives that allow representing sequences are: RDF containers (rdf:Seq in particular), ordered-list ontology[15] and OWL-List ontology [26]. RDF containers do not come with formal semantics which a Description Logic reasoner can make use of[16]. Ordered-list ontology makes use of index values of elements to maintain the order in a

[15] http://purl.org/ontology/olo/core#

[16] http://www.w3.org/TR/rdf11-mt/#rdf-containers

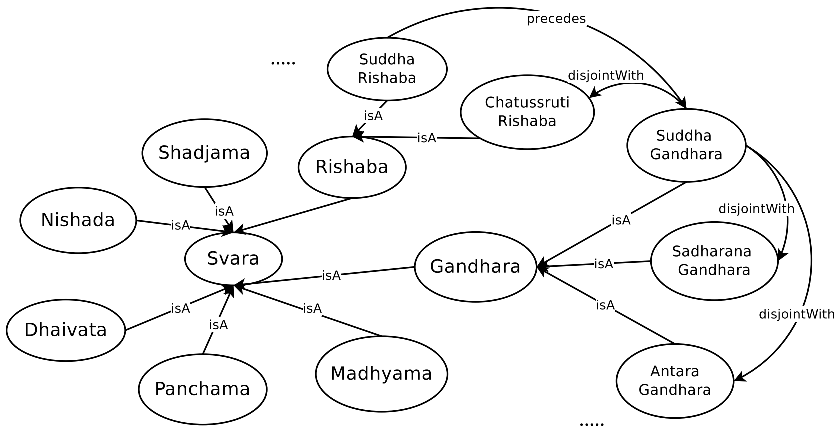

Fig. 2. A part of the svara ontology showing all the svaras, variants of a couple of svaras, and the relationships between them.

sequence, which limits the reasoning capabilities over the ontology. Therefore we chose to use OWL-List ontology to model the characteristic phrases of a rāga and it's ascending/descending progressions, which in essence are sequences of svaras. An OWL-List is analogous to a linked-list. It keeps the order of constituent svaras in a sequence and make inferences based on the properties which help maintain the order. This would allow to classify progressions into various subclasses, which would further allow to classify rāga using different schemes. Listing 3.2 shows an example sequence modeled using OWL-List ontology.

Listing 1.1. This is an example melodic sequence modeled using OWL-List ontology. This particular sequence shows part of a descending progression of svaras.

```
Progression
 and (hasContents exactly 1 Shadja)
 and (hasNext exactly 1
  (Progression
   and (hasContents exactly 1 Kakali_Nishada)
   and (hasNext exactly 1
      (Progression
    ...
      and (hasNext exactly 1
       (Progression
        and (hasContents exactly 1 Chatussruti_Rishaba)
      and (hasNext only EmptyList))))))
```

On the other hand, gamakas are not defined as a sequences of svaras. They are melodic movements, whose shape can vary depending on the context, given the rāga and the svaras around which they are sung. Therefore, the representation should allow for such contextual variations, which unfortunately cannot be enumerated. In fact, an audio sample is the closest representation for a gamaka. However, precisely determining the beginning and ending of a gamaka is not trivial. For this reason, we chose to model the gamakas as abstract sequences in which we do not specify the exact nature of gamaka in a direct manner. It is made a part of a longer sequence without an explicit indication of the beginning and the ending of gamaka within the sequence. Further, each sequence is linked to a segment of an audio recording which corresponds to a rendition of the sequence. This can be done using timeline ontology[17] or segment ontology [27]. The latter builds on the former to include semantics pertaining relations between temporal segments with properties such as *segmentBefore* and *segmentAfter*. Owing to its implied advantage in statistical and melodic analyses [28], we chose segment ontology. Fig. 3 shows the corresponding extension to melodic sequence ontology.

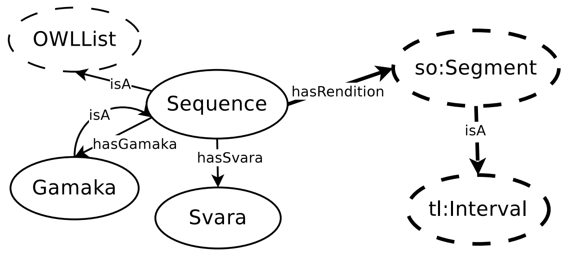

Fig. 3. The melodic sequence ontology extended with segment ontology to represent gamakas in the rāga ontology.

3.3 Rāgas

The rāga ontology engulfs sequence and svara ontologies to effect various classification schemes discussed in sec. 2. This is performed using a set of rules/conditions which when met, lead to the necessary classification. In a semantic web context, there is more than one way to do this: SPARQL Inferencing Notation (SPIN/SPARQL rules), Notation 3 rules, Rule Interchange Format (RIF), and Semantic Web Rule Language (SWRL). For the purpose of demonstration, we chose SPARQL rules (examples shown using SPARQL query syntax as opposed to SPIN syntax) to perform krama/vakra classification.

As mentioned in sec. 2, each rāga has two progressions - ascending and descending. A descent in an ascending progression, or an ascent in the descending progression makes the rāga a vakra rāga. Otherwise, it is classified as a krama rāga. In order to do this using our svara and melodic sequence ontologies, in each given descending progression, we check if a *ol:isFollowedBy* relationship exists between any two consequent svaras among *Shadja, Rishaba, Gandhara, Madhyama, Panchama, Dhaivata* and *Nishada*, in that order. Such relationship would mark an ascent pattern in descending progressions. This order of svaras is reversed and the operation is repeated for checking descent patterns in ascending progressions. Listing 4 shows an example SPARQL rule for the classification scheme. Besides these, svaras in a rāga have specific functional role [17]. These are modeled as direct relations from rāga to svaras (example: an object property *hasNyasaSvara* with *rāga* as domain, and *svara* as range).

[17] http://motools.sourceforge.net/timeline/timeline.html

4 Applications in computational analysis

Melodic and rhythmic analysis of Indian art music with an awareness of these concepts and their relationships would result in systems that are musically meaningful and reflective of the cultural aspects. For different music traditions studied as part of CompMusic project, we are building a navigational system called Dunya [29]. In this, the ontologies of musical concepts are one of the primary sources of information to determine the links between different recordings/concerts, or entities of music. For instance, given a rāga, it is used in finding other rāgas that have similar usage of a particular svara, say, by considering the transition probabilities in melodic sequences for different rāgas.

Listing 1.2. One of the several SPARQL rules used in the classification of rāgas into vakra/krama rāgas.

```

CONSTRUCT {?raaga a :vakraRaaga}
WHERE {
      {
        ?raaga :hasArohana ?progression.
        ?progression ol:hasContents :Gandhara.
        ?progression ol:isFollowedBy ?subsequentProgression.
        ?subsequentProgression ol:hasContents :Rishaba.
      }
      UNION
      {
        ?raaga :hasArohana ?progression.
        ?progression ol:hasContents :Gandhara.
        ?progression ol:isFollowedBy ?subsequentProgression1.
        ?progression ol:isFollowedBy ?subsequentProgression2.
        ?subsequentProgression1 ol:isFollowedBy ?subsequentProgression2
        ?subsequentProgression2 ol:hasContents :Gandhara.
        ?subsequentProgression2 ol:hasContents :Rishaba.
      }
  }
}
```

Further, it compliments and benefits the data analyses that goes into the description of various melodic and rhythmic aspects, such as intonation of svaras [23, 22] and melodic motifs (characteristic phrases) [30]. The description of a musical aspect obtained from the analysis of the audio recordings, interpreted with the help of the ontology, gives insights which otherwise are not obvious. For instance, the way a particular svara is intoned (say, the nature of semi-tonal oscillation which is very common in Carnatic music) can be identified by combining the intonation description (obtained from data analysis) and the nature of usage of svara in the rāga (obtained from ontology). The representation of gamaka in the rāga ontology implies an inevitable symbiotic loop with motivic analysis of audio recordings. For a given gamaka, melodic sequences similar to the ones which have the gamaka can be used to enhance/reinforce the prevailing representation of the gamaka in the ontology. In turn, the broad variety of sequences for a gamaka in the ontology can guide a supervised system to identify more similar sequences.

5 Conclusions & Future work

In this paper, we have presented the case for a knowledge-driven computational analysis of Indian art music. We discussed the rāga framework and some of the classification schemes from musicology. We presented a first version of the rāga ontology, and its intended applications in audio analysis and in the navigation of music collections. Modeling sequences, more specifically gamakas, is not trivial given the limitations on expressiveness of OWL-DL[18] and the variety of temporal variations possible for a given gamaka based on the context.

The rāga ontology need to be further extended to include: other classification schemes, differences in the definition of rāga based on school/lineage and historical periods etc. It is only possible to fully describe Indian art music by developing ontologies for other musical aspects. Of them, the two important aspects which we are addressing include: taala, the rhythmic framework, and compositional and improvisational forms. The latter, together with the rāga ontology would completely describe the melody in Indian art music. We are also working on using these ontologies to publish linked data of music collections put together in CompMusic project, and also using them with the data-driven approaches in an integrated manner.

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