KNOWLEDGE REPRESENTATION ISSUES IN MUSICAL INSTRUMENT ONTOLOGY DESIGN

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ABSTRACT

This paper presents preliminary work on musical instruments ontology design, and investigates heterogeneity and limitations in existing instrument classification schemes. Numerous research to date aims at representing information about musical instruments. The works we examined are based on the well known Hornbostel and Sach's classification scheme. We developed representations using the Ontology Web Language (OWL), and compared terminological and conceptual heterogeneity using SPARQL queries. We found evidence to support that traditional designs based on taxonomy trees lead to ill-defined knowledge representation, especially in the context of an ontology for the Semantic Web. In order to overcome this issue, it is desirable to have an instrument ontology that exhibits a semantically rich structure.

1. INTRODUCTION

Ontologies are used to represent knowledge in a formal way. For instance, they can be used to enable machines to make sense of the unstructured nature of information available on the Web. Compared to simple metadata encoding, ontologies provide meaning by defining concepts and relationships in an application domain, as well as constraints on their use. Furthermore, they permit interoperability, automatic reasoning and access to information using complex queries.

Knowledge representation in the domain of musical instruments is a complex issue, involving a wide range of instrument characteristics, for instance, physical aspects of instruments such as different types of sound initiation, resonators, as well as the player-instrument relationship. Since the 19th century, numerous studies developed systems for representing information about musical instruments, for instance, (ethno)musicologists have been working on creating a common vocabulary, which represents all instruments with relevant characteristics in a systematic way. The classification of instruments has also been investigated by organologists and museologists [8]. Hornobostel and Sachs [14] proposed a musical instrument classification scheme as an extension of Mahillon's scheme [9], originally designed to catalogue the worldwide collection of musical instruments housed in the Brussels Conservatory Instrumental museum.

The Hornobostel and Sachs classification scheme (H-S system) relies on a downward taxonomy by logical division. The method later coined Systematik by Dráger [4]. Although many attempts have since been made by scholars to improve the Hornobostel and Sachs' Systematik, it is still predominant in museums around the world. Kartomi [8] attributes the success of the classification system to the fact that it is essentially numerical rather than lexical, making it an international system (e.g. 211.11-922 refers to the timpani or kettledrum in the H-S system). Elschek [5], was the first to propose an upward method of classification based on instrument attributes complementing downward classifications schemes such as the Systematik.

The purpose of our paper is to investigate knowledge representation issues of musical instruments on the Semantic Web, by taking various musical instrument classification schemes into account. The rest of the paper is organised as follows: In section 2, we give an overview of the Semantic Web standards used in this study. In section 3, we describe the Music Ontology and the related instrument ontologies. In section 4, we detail knowledge representation issues of various musical instrument classification schemes, and highlight their conceptual heterogeneities. In section 5, the OWL representations of these classification schemes are examined using SPARQL queries. Finally, in the section 6, we note on further difficulties of the research problem, and outline our future work.

2. SEMANTIC WEB TECHNOLOGIES

The Semantic Web is an initiative of the World Wide Web Consortium (W3C) which proposes standards underlying the technologies of the Web [10]. The W3C investigates how to maintain interoperability and universality of the Web using open standards and languages. The technologies relevant in our examination of issues in musical instrument ontology design are presented in this section.

RDF: The Resource Description Framework (RDF) [1] is a simple data model, that associates *subjects* and *objects* using a *predicate*. A series of connections can be made using triples or three-tuple associations, which form a graph of semantic relationships. RDF is the basis for more complex knowledge representation languages such as the RDF Schema Language (RDFS). See for instance [2] for more details.

SKOS: The Simple Knowledge Organization Systems (SKOS) [2] is a semi-formal model for expressing controlled vocabularies (classification schemes, thesauri, taxonomies) in RDF. It defines `skos:Concept`, whose individuals may be associated with one or more lexical labels, `skos:prefLabel, skos:altLabel` and placed within a hierarchy using `skos:broader`, `skos:narrower`, or `skos:related` properties, exhibiting a thesaurus model [1].

OWL: The Ontology Web Language (OWL) [3] is a a W3C recommendation for defining and instantiating web ontologies. Like RDFS, OWL permits the definition of classes, properties and their instances, and is used to explicitly represent the meaning and relationships of terms in vocabularies, and express constraints on their use. Such a representation is called ontology. OWL has a richer vocabulary than RDFS and SKOS, for example, for specifying cardinality, equality, characteristics of properties such as transitivity or symmetry and enumerated classes. [1].

SPARQL: Simple Protocol and RDF Query Language (SPARQL) [4] defines a standard access protocol for RDF that provides Semantic Web developers with a powerful tool to extract information from large data sets. A query consists of several graph patterns, which can be combined recursively to form arbitrarily complex query patterns. It may be used for any data source that can be mapped to RDF.

[1] `http://www.w3.org/TR/rdf-primer`
[2] `http://www.w3.org/TR/skos-reference`
[3] `http://www.w3.org/TR/owl-primer`
[4] `http://www.w3.org/TR/rdf-sparql-protocol`

3. RELATED WORK

Our primary aim is to develop a semantically rich ontology of instruments which can be used in conjunction with the Music Ontology [5]. In this section, we outline this ontology and previously published Semantic Web ontologies of musical instruments.

The Music Ontology [13] provides a unified framework for describing music-related information (i.e. editorial data including artists, albums and tracks) on the Web. It is built on several ontologies such as the Timeline Ontology [6], the Event Ontology [7], the Functional Requirements for Bibliographic Records (FRBR) Ontology [8], and the Friend Of A Friend (FOAF) Ontology [9]. It subsumes specific terms from these ontologies, useful to describe music related data. The Timeline and Event ontologies, can be used to localise events in space and time. The FRBR model links books and other intellectual works with their creators, publishers or subjects, and provides a model to describe the life cycle of these works. This is reused by the Music Ontology to describe the music production workflow from composition to delivery. Finally, FOAF defines people, groups and organisations. The Music Ontology does not cover every music related concept, rather, it provides extension points where a domain specific ontology, such as a musical instrument or a genre ontology may be integrated.

Based on the Musicbrainz [10] instrument tree, Herman [11] published a musical instrument taxonomy expressed in SKOS. This serves as an extension to the Music Ontology. While SKOS is well suited for hierarchical classification schemes, it provides limited support for other types of relationships; `skos:related` for example, may be used to describe associative relations, but only in a semi-formal way, without a more explicit definition. Moreover, the transitivity of broader and narrower relations are not guaranteed in SKOS, therefore it is difficult to infer for instance the instrument family of a given instrument, without additional knowledge not expressed in the model. While this taxonomy is suitable for applications that require only a semantic label to represent instruments associated with audio items, it is insufficient if the heterogeneity of instrument relations has to be explicitly represented.

The Kanzaki Music Ontology [12] also contains a small instrument taxonomy. However, there are only 5 instru-

[5] `http://musicontology.com/`
[6] `http://purl.org/NET/c4dm/timeline.owl/`
[7] `http://purl.org/NET/c4dm/event.owl/`
[8] `http://vocab.org/frbr/core/`
[9] `http://xmlns.com/foaf/spec/`
[10] `http://musicbrainz.org/`
[11] `http://purl.org/ontology/mo/mit#`
[12] `http://www.kanzaki.com/ns/music`

ment families defined (e.g. string instruments, woodwind instruments, brass instruments, percussion, and keyboard instruments), with 26 corresponding instrument classes. Although these works provide instrument taxonomies that can be used on the Semantic Web, there remains a need for a semantically rich ontology, which represents the heterogeneity as well as different components and aspects of musical instruments on the Web.

Finally, a recently published XML-based taxonomy serves as an extension to Music XML [13] . This system departs form Hornobostel and Sachs, and proposes a classification scheme based on materials and performance mechanism, instead of the sound production mechanism. However, it remains at a hierarchical design. Furthermore, XML in itself is insufficient for rich knowledge representations, therefore it is hard to see how this model may be extended to account for the heterogeneity and the diverse set of properties of musical instruments, and enable logical reasoning or answering complex queries.

4. ISSUES IN MUSICAL INSTRUMENT ONTOLOGY DESIGN

Conceptualising a domain is inherent in developing knowledge based systems. In the fields of ethno-musicology and Music Information Retrieval (MIR), most conceptualisations of the domain of musical instruments are based on the taxonomical H-S system, and very few studies departed from this system. Taxonomies allow us to organise data in a hierarchical structure very efficiently. However, taxonomies encode a strict relationship between a parent node and a child node by using *sub-class* or *part-of* axioms, without defining the detailed relationships among instrument objects, therefore they are semantically weak structures for expressing knowledge [3, 6, 7]. Musical instruments however have a multi-relational model, thereby instruments can belong to more than one instrumental family or subfamily. In order to illustrate the heterogeneity and taxonomic design problems occurring in current knowledge representations of instruments, two different instrument classification systems were taken into account: i) one proposed by Henry Doktorski [14] which will be denoted taxonomy 'A', and ii) one proposed by Jeremy Montagu & John Burton [11] which will be denoted taxonomy 'B'. We implemented both of the taxonomies in OWL, and they can be found at corresponding URL [15] . Figure 1 illustrates an example from the ontology design of the chordophones/string instrument family based on Henry Doktorski's taxonomy.

[13] http://www.recordare.com/musicxml/
[14] http://free-reed.net/description/taxonomy
[15] http://isophonics.net/content/musical-instrument-taxonomies

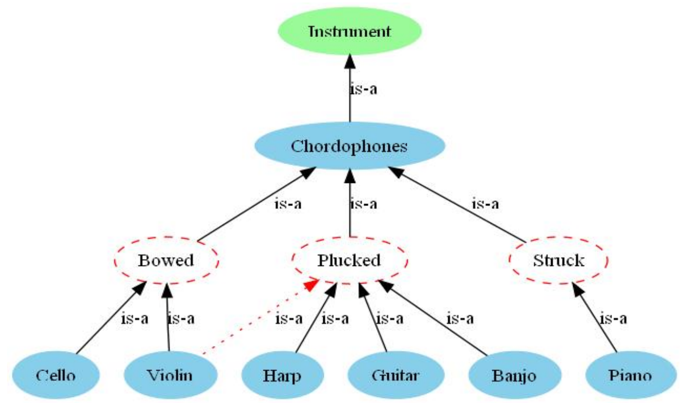

Figure 1. An example from musical instrument ontology design of chordophone/string instruments based on Henry Doktorski's instrument classification system

As shown in Figure 1, the violin and cello are classified as bowed instruments, the guitar and banjo are classified as plucked instruments, and the piano is classified as a struck instrument. However, violinist can vary their playing technique depending on the expressive intentions: the strings can be excited by drawing the hair of the bow across them (arco), or by plucking them (pizzicato). For these reasons, the violin should be classified as either a bowed or plucked instrument. In Figures 1 and 2, the concepts that occurred multiple times in various instrument families, are shown using dashed lined shapes (e.g. struck, plucked and rubbed). We can demonstrate similar examples in the family of percussion instruments. For instance, in Figure 2, the tambourine is classified as a membranophone, whereas if it is only shaken, it jingles, and therefore it could be classified as an idiophone as well. Many examples may be observer related to taxonomic classification problems, not only in the ethno-musicology, but also in other applications that rely on musical instrument knowledge representation or information management.

In taxonomy B, the use of classifications such as, *species*, *genus*, *family*, *sub-order*, *order*, based on the taxonomical system of Carl Linnaeus known as the father of modern taxonomy. However, this study only provides a terminological departure from the H-S system, since it is still based on the same taxonomy structure. A partial instrument ontology design of this classification scheme is depicted in Figure 3.

The use of different words to refer to similar concepts, or different conceptualisations, induce terminological or conceptual heterogeneities among ontologies, that can be observed from the given graphical illustrations so far. For instance, in Figure 3, the idiophones and the membranophones are defined as a major instru-

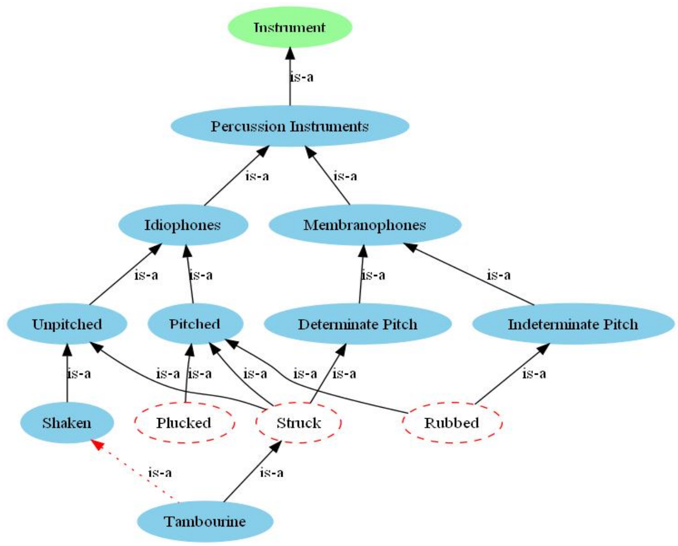

Figure 2. An example from musical instrument ontology design of percussion instruments based on Henry Doktorski's instrument classification system

ment family according to taxonomy B, whereas both of these classes can be seen as sub-classes of the percussion instruments in taxonomy A (Figure 2).

The heterogeneity among these classes continues downward towards to the sub-class nodes: For instance, *idiophones* are divided into unpitched and pitched subcategories, while *membranophones* are divided into determinate pitch and indeterminate pitch sub-categories (Figure 2). On the other hand, the *idiophones* have subclasses such as struck, shaken, striligilated and plucked sub-classes, while *membranophones* have kettle, single head and double head sub-classes (Figure 3). Some concepts are present in the same taxonomic level without defining the relationship among concepts, and the concepts are classified according to sound initiation type (e.g. struck, plucked, or shaken), whereas others are classified according to the instrument construction type (e.g. single head, double head, harps, lyres and lutes). Therefore, the taxonomic classifications applied traditionally are not only heterogeneous in structure, but also provide an arbitrarily problematic solution to instrument classification, because of the inadequately defined knowledge representation.

5. QUERY DRIVEN EVALUATION

Both taxonomies described in the previous section were implemented in OWL and tested using SPARQL queries involving instruments present in both systems. In the following examples, we query the ontology structure, as well as RDF data corresponding to specific statements about instruments. Since in most knowledge-based environments, data and ontology can be represented in the same graph, these queries also demonstrate real-world use cases for instrument knowledge representation. The first example is based on the *tuba*, which is available in both taxonomies. The following paragraph taken from [12] provides a description of the tuba:

> *The tuba is the lowest pitched Aerophone. Sound is produced by vibrating or buzzing the lips into a large cupped mouthpiece, which is coupled to a coiled tube about 18 feet in length with a slow rate of conical flare terminating in a large bell-shaped mouth. The tuba is usually equipped with three valves, each of which adds a different length of tubing. With piston valves it is possible to change the length of the air column.*

Identifying an instrument by its sound can be a difficult task, even for someone with a decent musical background. For this reason, visual cues can be just as important as hearing in instrument identification. For example, recognising the characteristic shape of an instrument is important, since it has a profound effect on the generated sound. Based on these considerations, we prepared the following four queries to retrieve the information underlined in the definition of the tuba above: What is the instrument family, the characteristic shape, the sound initiation type and the number of valves of the tuba?

```
PREFIX io: <http://example.org/io/taxonomyN#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT ?x WHERE { io:Tuba rdfs:subClassOf ?x }
```

Listing 1. Retrieving the immediate super class of the tuba.

In the first query the non-determined variable `?x` is assigned when the query engine finds the super class of the entity named *Tuba*. The query result for taxonomy *'A'* is `io:WithValves`, and for taxonomy *'B'* is `io:ValvesBugles`. This demonstrates terminological heterogeneity immediately on the first upper level. Note that name space prefixes such as `io:` and `rdfs:` are expanded to full URIs by the query engine. In the following queries, they will be omitted for brevity.

In order to retrieve the instrument family, we can either expand the query until we reach the corresponding node as shown in listing 2, or use a program to do so appropriately. This assumes knowledge about the depth and organisation of the taxonomy tree, that is, what information is described on each level given a specific branch. Given this information, a reasoning engine could infer the instrument family relation, so that

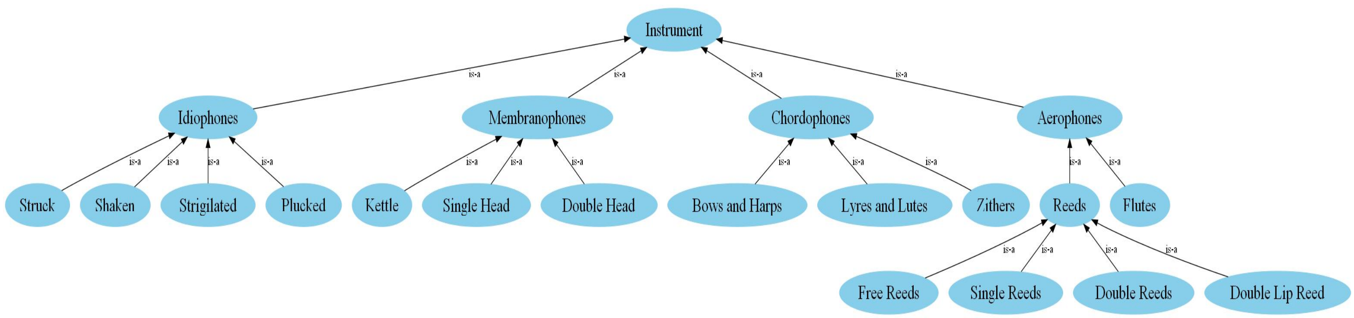

Figure 3. An example from musical instrument ontology design based on Jeremy Montagu & John Burton's instrument classification system

```
SELECT ?sc1 ... ?sc(N)
 WHERE { io:Tuba rdfs:subClassOf ?sc1 .
  OPTIONAL { ?sc1 rdfs:subClassOf ?sc2 } .
          .
          .
  OPTIONAL { ?sc(N-1) rdfs:subClassOf ?sc(N) } .
}
```

Listing 2. Hypothetical query for finding the instrument family of the tuba.

a direct query could be written. However, taxonomy based knowledge organisation systems do not contain this type of information, which is their main drawback in answering complex queries.

Intuitively, this query graph means that there exists an entity *Tuba* that is a subclass of *?sc1* having a relation with another entity whose name is non-determined. We may recursively go on until finding the entity *Aerophones*, the super-class of the last non-determined class. The query would succeed at the 4th super-class node for the taxonomy 'A' (e.g.*WithValves, BrassInstrument, PipeAerophones, Aerophones*), whereas the corresponding result would be obtained at the 10th node for the taxonomy 'B' (e.g.*ValvedBugles, SingleBell, Valves, EndBlown, Metal, Conical, DoubleLipReed, Reeds, Aerophones*).

The main problem with taxonomical representations is that it's difficult to answer certain queries without a more explicit knowledge representation. Taxonomic systems propagate meaning via the parent child relationship. We could infer that the tuba is an (*is-a*, or `rdf:type`) instrument with *Valves*, a *Brass instrument* and an *Aerophone*, according to taxonomy 'A'. The instrument family could be directly encoded using a semantically rich ontology. Although both taxonomies are based on the H-S system, it is easy to observe the diversity among different instrument taxonomies from these query results. The problem is not only the conceptual heterogeneity of the instruments themselves, but also the terminological heterogeneity among different knowledge representation schemes.

```
@prefix io: <http://example.org/io/taxonomyN#>
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix mo: <http://purl.org/ontology/owl/> .
@prefix ex: <http://example.com/> .

ex:guy_klucevsek
  a mo:MusicArtist ;
  foaf:name "Guy Klucevsek" ;
  owl:sameAs <http://dbpedia.org/page/Guy_Klucevsek> ;

ex:guy_klucevseks_accordion
  a io:Accordion .

ex:ellltl
  a mo:Composition ;
  dc:title "Eleven Large Lobsters Loose in the Lobby"^^xsd:string ;
  mo:composer ex:guy_klucevsek ;
  mo:produced_work ex:w_ellltl;
  owl:sameAs
<http://dbtune.org/musicbrainz/page/track/8093f69e-194f-4cb1-8943-2d11fac

ex:p_ellltl
  a mo:Performance ;
  rdfs:label "A performance of the composition."^^xsd:string ;
  mo:performer ex:guy_klucevsek ;
  mo:performance_of ex:w_ellltl ;
  mo:instrument ex:guy_klucevseks_accordion .
```

Listing 3. RDF Data based on Music Ontology and Music Instrument Taxonomy (Herny Doktorski).

The second query is *'What is the characteristic shape of the tuba?'*. To find this information, an upward recursive query, such as the one in Listing 2, or downward recursive query, which starts from the *Conical* concept, can be used to verify that the tuba is a conical instrument. However, both types of queries rely on external knowledge that can not be inferred from the pure taxonomical relationships directly. While taxonomy *'B'* at least contains the information about the characteristic shape of the tuba, being *Conical*, taxonomy *'A'* does not contain this information. In the third and fourth questions, we ask *'What is the sound initiation type of the* *tuba ?'* and *'How many valves the tuba has?'*. Unfortunately none of the implemented systems encode these relationships, therefore it is not possible to write queries to answer these questions that would produce any results.

In our second example shown in listing 3, we use the Music Ontology to represent the *Composition* and *Performance* events from the sentence below, assuming the composer also performed the piece:

The American accordionist and composer Guy Klucevsek has written a piece for solo accordion, 'Eleven Large Lobsters Loose In The Lobby', which does not use the reeds of the accordion. The performer produces sounds by clicking the register switches, tapping the keys, and other percussive means. In this piece the accordion is used as an idiophone and not as a free-reed.

This example presents a case for knowledge discovery using instrument taxonomies. As shown in the example, lacking a more detailed ontological representation, we could not describe the accordion further to take into account the specific playing style. Since none of the taxonomies may be used to encode information about possible alternative sound initiation types, we may only obtain the instrument's default characteristics given a taxonomy, using recursive queries such as query 2. Given this representation a reasoner can only infer that the Accordion is a *Hand blown, Free-reed, Aerophone* instrument. However, in this particular example, the instrument was played using different techniques, such as clicking the register switches and tapping the keys, which implies its use as an idiophone. The inductive challenge is to infer statements about the relations and objects that are true but unobserved. Due to the drawbacks of traditional taxonomies, the reasoner would not be able to discover new knowledge about the particular individual played as an idiophone in this specific example.

6. CONCLUSION

In this study, we investigated some issues arising in the representation of knowledge about musical instruments. In order to demonstrate their drawbacks in complex query answering, we implemented two instrument taxonomies based on the well-known H-S system in OWL. We found that many instrument classification schemes exhibit insufficient or ill-defined semantics for our purposes, thus a more flexible representation is required. We demonstrated using different SPARQL queries that depending on the terminology and conceptualisation used by (ethno)musicologists, we obtain different results for the same instrument object. It also became evident, that ontologies that define relationships between entities are better than traditional taxonomies at providing meaningful answers to queries. Our work however represents only a preliminary analysis of current musical instrument schemes. Future work includes developing a musical instrument ontology, and further investigation on how to represent heterogeneous instrument classifications in a Semantic Web environment.

7. REFERENCES

[1] Dean Allemang and Jim Hendler. *Semantic Web for the Working Ontologists*. Morgan Kaufmann, 2008.

[2] Grigoris Antoniou and Frank can Harmelen. *Semantic Web Premier 2nd Edition*. Massachusetts Institute of Technology, 2008.

[3] Michael C. Daconta, Leo J. Obrst, and Kevin T. Smith. *The Semantic Web: A Guide to the Future of XML Web Services, and Knowledge Management*. Wiley Publishing, 2003.

[4] Hans Heinz Drâger. Prinzip einer systematik der musikinstrumente. *Kassel und Basel:Barenreiter.*, 1948.

[5] Oskár Elschek. System of graphical and symbolic signs for the typology of aerophones. *Bratislava:VydatelstvS lovenskej Academi Vied.*, 1969.

[6] Martin Hepp. Representing the hierarchy of industrial taxonomies in OWL:the gen/tax approach. *ISWC Workshop Semantic Web Case Studies and Best Practices for eBusiness (SWCASE05)*, 2005.

[7] Martin Hepp and Jos de Bruijn. Gentax: A generic methodology for deriving OWL and RDF-S ontologies from hierarchical classifications, thesauri, and inconsistent taxonomies. *The Semantic Web: Research and Applications, Lecture Notes in Computer Science*, 4519/2007:129–144, 2007.

[8] Margaret Kartomi. The classification of musical instruments: Changing trends in research from the late nineteenth century, with special reference to the 1990s. *Ethnomusicology*, 45:283–314, 2001.

[9] Rene T. A. Lysloff and Jim Matson. A new approach to the classification of sound-producing instruments. *Ethnomusicology*, 29:213–236, 1985.

[10] Brian Matthews. Semantic web technologies. *JISC Technology and Standards Watch*, 2005.

[11] Jeremy Montagu and John Burton. A proposed new system for musical instruments. *Society for Ethnomusicology*, 15:49–70, 1971.

[12] Harry F. Olson. *Music, Physics and Engineering*. Dover Publications, 1967.

[13] Yves Raimond. *A Distributed Music Information System*. PhD thesis, Queen Mary University of London, 2008.

[14] Erich Moritz von Hornbostel and Curt Sachs. Systematik der musikinstrumente: Einversuch. Zeitschriftffir Ethnologie, Translated by A. Baines and K. Wachsmann as A Classification of Musical Instruments. *Galpin Society Journal.*, 1914.