Semantic Integration and Retrieval of Multimedia Metadata

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Abstract. The amount of digital media that has to be actually managed has already become unaffordable without fine-grained computerised support. This requires an extensive use of multimedia metadata. MPEG-7 is the greatest metadata framework created to date but it is based on XML Schemas. Therefore, its does not have formal semantics, which makes difficult to manage, extend and integrate it. Consequently, there have been a lot attempts to move MPEG-7 to the Semantic Web.

Our approach contributes a complete and automatic mapping of the whole MPEG-7 standard to OWL. It is based on a generic XML Schema to OWL mapping. The previous mapping is complemented with an XML metadata instances to RDF mapping that completes a transparent transfer of metadata from the XML to the Semantic Web domain.

Once in a semantic space, data integration, which is a crucial factor when several sources of information are available, is facilitated enormously. We have used the generated MPEG-7 OWL ontology as an "upper-ontology" for multimedia metadata, where three different music schemas have been linked. Thus, it has been possible to retrieve related information from instances of all the metadata sources. Furthermore, detecting and merging instances from different sources has allowed us to enhance the description of audio files, both content-based and editorial data.

1 Introduction

During the last decades, digital media has been a revolution for media reproduction. This, in combination with the media distribution break-up carried out by the World Wide Web, has produced an explosion of the media availability. The amount of digital media that has been generated and stored, and which continues to do so at an exponential rate, has already become unmanageable without fine-grained computerised support. Low-level approaches, based on signal analysis, are proving to be extremely limiting in making multimedia database systems accessible and useful to end-users. These content-based descriptors lay far away from what users recognise as media description means [1]. Consequently, recent research has begun to focus on bridging the semantic and conceptual gap that exists between user and computer –from content-based to high-level descriptions.

One approach to overcome this gap is knowledge-based techniques based on Web ontologies. As formal and web-wide shared conceptualisations, ontologies facilitate automated integration and meaningful retrieval of multimedia –both content and metadata– from different sources.

We have tested the Web ontologies approach in previous research projects, in the more concrete context of metadata for Digital Rights Management [2,3]. In this paper, we are going to do the same in the broader scope of the digital media field. The greatest limitation, as our exploration of the multimedia metadata state of the art has shown [4], is that metadata is scarce and expensive to produce. We overcome this barrier moving the more mature MPEG-7 multimedia standard to the Semantic Web. MPEG-7 [5], formally named Multimedia Content Description Interface, is the main multimedia metadata initiative and aims to create a standard for the description of the multimedia content that supports some degree of interpretation of the information's meaning. However, MPEG-7 does not incorporate formal semantics in its schemas, and it is based on XML syntactic metadata.

In order to add semantics to MPEG-7 metadata we use an XML Schema to Web Ontology mapping and a transformation from XML instances to RDF semantic metadata. After that, we show that in the Semantic Web framework it is easier to integrate multimedia metadata coming from disparate sources and exploit the implicit semantics for intelligent retrieval. Finally, once all metadata has been integrated, advanced ontologies and semantic rules are used to encode the necessary semantics to derive high-level concepts from content-based descriptions. This altogether can dramatically increase multimedia retrieval accuracy and it makes possible advanced services over complex multimedia repositories, e.g. fine-grained multimedia digital rights management, assisted multimedia authoring by composition, accurate media recommendation systems –based on both content and context descriptors–, etc.

2 Multimedia Metadata

As it has been introduced and it is extensively shown in the literature [6,7,8,9], the MPEG-7 standard constitutes the greatest effort for multimedia description. It is divided into four main components: the Description Definition Language (DDL, the basic building blocks for the MPEG-7 metadata language), Audio (the descriptive elements for audio), Visual (those for video) and the Multimedia Description Schemes (MDS, the descriptors for capturing the semantic aspects of multimedia contents, e.g. places, actors, objects, events, etc.).

MPEG-7 is implemented by XML Schemas. The set of MPEG-7 XML Schemas defines 1182 elements, 417 attributes and 377 complex types. The size of this standard makes it quite difficult to manage. Moreover, the use of XML technologies implies that a great part of the semantics remains implicit. Therefore, each time a

MPEG-7 application is developed, semantics must be extracted from the standard and re-implemented.

For instance, if we use XQuery in order to retrieve MPEG-7 *SegmentType* descriptions from an XML database, we must be aware of the hierarchy of segment types and implement an XQuery that has to cover any kind of multimedia segment, i.e. *VideoSegmentType*, *AnalyticClipType*, *AudiSegmentType*, etc. Once the hierarchy of segments types is available in Web Ontology Language (OWL) form, semantic queries benefit from the, now, explicit semantics. Therefore, a semantic query for SegmentType will retrieve all subclasses without requiring additional developing efforts.

This is necessary because, although XML Schemas capture some semantics of the domain they model, XML tools are based on syntax. The captured semantics remain implicit from XML processing tools point of view. Therefore, when an XQuery searches for a *SegmentType*, the XQuery processor has no way to know that there are many other kinds of segment types that can appear in its place, i.e. they are more concrete kinds of segments.

The previous example only illustrates one kind of difficulty derived from the use of just syntax-aware tools. MPEG-7 constitutes a valuable starting point for more specific developments, i.e. it can be seen as an "upper-ontology" for multimedia. However, the lack of explicit semantics makes MPEG-7 very difficult to extend in an independent way, i.e. third party extensions. This lack of facilities for easy extension has been one of the main motivations to build solutions that make MPEG-7 semantics formal and thus easily machine-processable. These and other solutions are detailed in the next subsection. After that, our approach is introduced.

2.1 Semantic Multimedia Metadata Initiatives

Chronologically, the first attempts to make MPEG-7 metadata semantics explicit where carried out, during the MPEG-7 standardisation process, by Jane Hunter [10]. The proposal used RDF to formalise a small part of MPEG-7, and later incorporated some DAML+OIL construct to further detail their semantics [11]. However, at that moment, there were not mature technologies for Web-wide metadata semantics formalisation. Moreover, XML had already a great momentum, so it was the logical choice.

From this point, once Semantic Web has matured, there have been more attempts to relate MPEG-7 with Web ontologies. However, none of them has retaken the initial effort to completely move MPEG-7 to the Semantic Web. This initiatives range from separated modules for existing MPEG-7 tools that offer reasoning capabilities for concretes aspects of multimedia management [7], to a partial OWL modelling of the MPEG-7 Multimedia Description Schemes intended to facilitate MPEG-7 extensions [9]. Moreover, they are not systematic; they are applied on an ad-hoc basis, what makes them very costly to apply to the whole MPEG-7 standard.

The previous initiatives have produced very interesting results and are complementary to our objective, i.e. to move the whole MPEG-7 to the Semantic Web. This way, we would have a core multimedia ontology that facilitates further extensions and reasoning capabilities, but also a complete semantics-aware solution for MPEG-7 metadata processing. The method we have used to perform this is detailed in the next section. It is a generic XML Schema to OWL mapper combined with an XML to RDF translator. It has already shown its usefulness with other quite big XML Schemas in the Digital Rights Management domain, such as MPEG-21 [12] and ODRL [13].

3 Moving Metadata to the Semantic Web

The main caveat of semantic multimedia metadata is that it is sparse and expensive to produce. The previously introduced initiatives are appropriate when applied to limited scopes. However, if we want to increase the availability of semantic multimedia metadata and, in general, of semantic metadata, we need methods that are more productive. The more direct solution is to take profit from the great amount of metadata that has been already produced by the XML community.

There are many attempts to move metadata from the XML domain to the Semantic Web. Some of them just model the XML tree using the RDF primitives [14]. Others concentrate on modelling the knowledge implicit in XML languages definitions, i.e. DTDs or the XML Schemas, using web ontology languages [15,16,17]. Finally, there are attempts to encode XML semantics integrating RDF into XML documents [18,19].

However, none of them facilitates an extensive transfer of XML metadata to the Semantic Web in a general and transparent way. Their main problem is that the XML Schema implicit semantics are not made explicit when XML metadata instantiating this schemas is mapped. Therefore, they do not take profit from the XML semantics and produce RDF metadata almost as semantics-blind as the original XML. Or, on the other hand, they capture these semantics but they use additional ad-hoc semantic constructs that produce less transparent metadata.

Therefore, we have chosen the ReDeFer[1] approach that combines an XML Schema to web ontology mapping, called XSD2OWL, with a transparent mapping from XML to RDF, XML2RDF. The ontologies generated by XSD2OWL are used during the XML to RDF step in order to generate semantic metadata that makes XML Schema semantics explicit. Both steps are detailed next.

3.1 XSD2OWL Mapping

The XML Schema to OWL mapping is responsible for capturing the schema implicit semantics. This semantics are determined by the combination of XML Schema constructs. The mapping is based on translating this constructs to the OWL ones that best capture their semantics. These translations are detailed in Table 1.

The XSD2OWL mapping is quite transparent and captures a great part XML Schema semantics. The same names used for XML constructs are used for OWL ones, although in the new namespace defined for the ontology. XSD and OWL constructs names are identical; this usually produces uppercase-named OWL

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[1] ReDeFer, http://rhizomik.upf.edu/redefer

properties because the corresponding element name is uppercase, although this is not the usual convention in OWL.

Therefore, XSD2OWL produces OWL ontologies that make explicit the semantics of the corresponding XML Schemas. The only caveats are the implicit order conveyed by *xsd:sequence* and the exclusivity of *xsd:choice*.

For the first problem, *owl:intersectionOf* does not retain its operands order, there is no clear solution that retains the great level of transparency that has been achieved. The use of RDF Lists might impose order but introduces ad-hoc constructs not present in the original metadata. Moreover, as it has been demonstrated in practise, the element´s' ordering does not contribute much from a semantic point of view. For the second problem, *owl:unionOf* is an inclusive union, the solution is to use the disjointness OWL construct, *owl:disjointWith*, between all union operands in order to make it exclusive.

Table 1. XSD2OWL translations for the XML Schema constructs and shared semantics with OWL constructs

XML Schema	OWL	Shared informal semantics
element | attribute	rdf:Property owl:DatatypeProperty owl:ObjectProperty	Named relation between nodes or nodes and values
element@substitutionGroup	rdfs:subPropertyOf	Relation can appear in place of a more general one
element@type	rdfs:range	The relation range kind
complexType|group |attributeGroup	owl:Class	Relations and contextual restrictions package
complexType//element	owl:Restriction	Contextualised restriction of a relation
extension@base | restriction@base	rdfs:subClassOf	Package concretises the base package
@maxOccurs @minOccurs	owl:maxCardinality owl:minCardinality	Restrict the number of occurrences of a relation
sequence choice	owl:intersectionOf owl:unionOf	Combination of relations in a context

The XSD2OWL mapping has been applied to the MPEG-7 XML Schemas producing a MPEG-7 Ontology[2]. This ontology has 2372 classes and 975 properties. The only adjustment that has been done to the automatically generated ontology is to resolve a name collision between an OWL class and a RDF property. This is due to the fact that XML has independent name domains for complex types and elements while OWL has a unique name domain for all constructs.

Moreover, the resulting OWL ontology is OWL-Full because the XSD2OWL translator has employed *rdf:Property* for those xsd:elements that have both data type and object type ranges.

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[2] MPEG-7 Ontology, http://rhizomik.upf.edu/ontologies/mpeg7ontos

3.2 XML2RDF Mapping

Once all the metadata XML Schemas are available as mapped OWL ontologies, it is time to map the XML metadata that instantiates them. The intention is to produce RDF metadata as transparently as possible. Therefore, a structure-mapping approach has been selected [14]. It is also possible to take a model-mapping approach [20]. XML model-mapping is based on representing the XML information set using semantic tools. This approach is better when XML metadata is semantically exploited for concrete purposes. However, when the objective is semantic metadata that can be easily integrated, it is better to take a more transparent approach.

Transparency is achieved in structure-mapping models because they only try to represent the XML metadata structure, i.e. a tree, using RDF. The RDF model is based on the graph so it is easy to model a tree using it. Moreover, we do not need to worry about the semantics loose produced by structure-mapping. We have formalised the underlying semantics into the corresponding ontologies and we will attach them to RDF metadata using the instantiation relation *rdf:type.*

The structure-mapping is based on translating XML metadata instances to RDF ones that instantiate the corresponding constructs in OWL. The more basic translation is between relation instances, from *xsd:elements* and *xsd:attributes* to *rdf:Properties*. Concretely, *owl:ObjectProperties* for node to node relations and *owl:DatatypeProperties* for node to values relations.

However, in some cases, it would be necessary to use *rdf:Properties* for *xsd:elements* that have both data type and object type values. Values are kept during the translation as simple types and RDF blank nodes are introduced in the RDF model in order to serve as source and destination for properties. They will remain blank for the moment until they are enriched with semantic information.

The resulting RDF graph model contains all that we can obtain from the XML tree. It is already semantically enriched thanks to the *rdf:type* relation that connects each RDF properties to the *owl:ObjectProperty* or *owl:DatatypeProperty* it instantiates. It can be enriched further if the blank nodes are related to the *owl:Class* that defines the package of properties and associated restrictions they contain, i.e. the corresponding *xsd:complexType.* This semantic decoration of the graph is formalised using *rdf:type* relations from blank nodes to the corresponding OWL classes.

At this point we have obtained a semantics-enabled representation of the input metadata. The instantiation relations can now be used to apply OWL semantics to metadata. Therefore, the semantics derived from further enrichments of the ontologies, e.g. integration links between different ontologies or semantic rules, are automatically propagated to instance metadata thanks to inference. We will show now how this mapping fits in the architecture for semantic multimedia metadata integration and retrieval.

However, before continuing to the next section, it is important to point out that these mappings have been validated in different ways. First, we have used OWL validators in order to check the resulting ontologies, not just the MPEG-7 Ontology but also many others [12,13]. Second, our MPEG-7 ontology has been compared to Jane Hunter's one [11]. This comparison has shown that our mapping captures the same semantics as those captured by hand, by Jane Hunter, using RDF Schema and DAML+OIL. Finally, the two mappings have been tested in conjunction. Testing

XML instances have been mapped to RDF, guided by the corresponding OWL ontologies from the used XML Schemas, and then back to XML. Then, the original and derived XML instances have been compared using their canonical version in order to correct mapping problems.

4 System architecture

Based on the previous XML world to Semantic Web domain mapping, we have built up a system architecture that facilitates multimedia metadata integration and retrieval. The architecture is sketched in Fig. 1. The MPEG-7 OWL ontology, generated by XSD2OWL, constitutes the basic ontological framework for semantic multimedia metadata integration and appears at the centre of the architecture. Other ontologies and XML Schemas might be easily incorporated using the XSD2OWL module.

Semantic metadata can be directly fed into the system together with XML metadata, that is made semantic using the XML2RDF module. XML MPEG-7 metadata has a great importance because it is commonly used for (automatically extracted) low-level metadata that constitutes the basic input of the system.

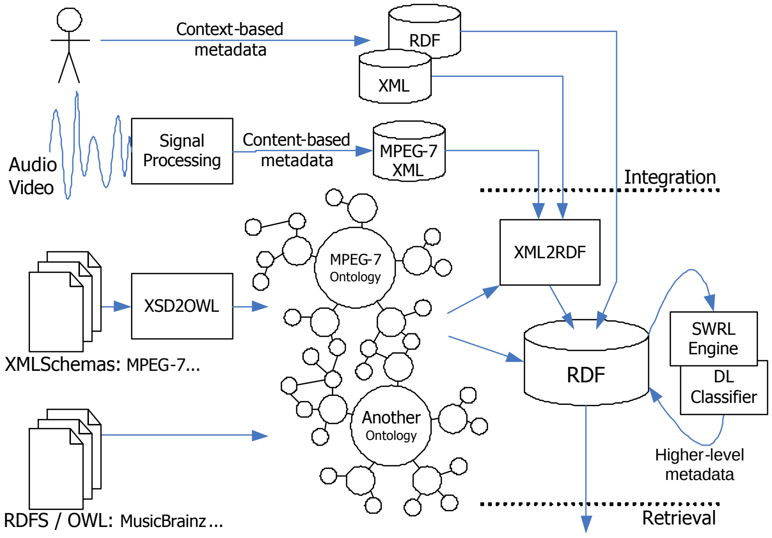

Fig. 1. Metadata integration and retrieval architecture

This framework has the persistence support of a RDF store, where metadata and ontologies reside. Once all metadata has been put together, the semantic integration can take place, as detailed in section 4.1. Finally, from this integrated space, higher-level metadata can be inferred and retrieved, as shown in section 4.2.

4.1 Semantic Integration

As mentioned in the introduction, the problem of integrating heterogeneous data sources has grown in importance within the last years. One of the main reasons is the increasing availability of web-based data sources. Even within a single organization, data from disparate sources must be integrated. Our approach to solve this problem is based on Web ontologies. As we focus on integration of multimedia assets, our base ontology is the MPEG-7 OWL ontology.

When multimedia metadata based on different schemes has to be integrated, the XML Schemas are first mapped to OWL. Once this first step has been done, these schemas are easily integrated into the ontological framework using OWL semantic relations for equivalence and inclusion: *subClassOf*, *subPropertyOf*, *equivalentClass*, *equivalentProperty*, *sameIndividualAs*, etc. These relationships capture the semantics of the data integration. Then, once metadata is incorporated into the system and semantically-decorated, the integration is automatically performed by applying inference.

Our study on metadata integration is based on three different schemas: MusicBrainz[3] schema, Simac music ontology[4] and a music vocabulary to describe performances[5]. MusicBrainz is a community music metadatabase that attempts to create a comprehensive music information site. MusicBrainz schema is written in RDF, and describes all the tracks, albums and artists available in their music repository. Their mappings to the MPEG-7 OWL ontology are shown in Table 2.

Table 2. MusicBrainz to MPEG-7 OWL ontology mappings

```
  musicbrainz:Artist ⊆ mpeg7:CreatorType
   musicbrainz:Album ⊆ mpeg7:CollectionType
   musicbrainz:Track ⊆ mpeg7:AudioSegmentType
           dc:author ⊆ mpeg7:Creator
            dc:title ⊆ mpeg7:Title
musicbrainz:sortName ⊆ mpeg7:Name
musicbrainz:duration = mpeg7:MediaDuration
```

Simac music ontology describes (low-level) content-based descriptors extracted automatically from the audio itself. The mappings of this schema to the MPEG-7 OWL ontology are summarized in Table 3. An artist is defined as a subclass of the MPEG-7 Creator type, a track is defined as a subclass of the MPEG-7 AudioSegment and the audio Descriptor class describes the content-based properties of a track. This descriptor is linked with the MPEG-7 AudioDS type. Thus, all Simac descriptors' subclasses inherit the properties from the MPEG-7 Audio descriptor scheme. To characterize the descriptors related with the tonality of a song, Simac ontology defines some properties, such as mode and key. Finally, Simac ontology defines rhythm descriptors to describe the rhythm component of a track, e.g. meter.

The last of the three schemas, a music vocabulary to describe performances, is linked, as well with the MPEG-7 OWL (see Table 4). This schema models –for

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[3] http://musicbrainz.org/mm/mm-2.1#

[4] http://www.semanticaudio.org/ontologies/music/2005/04/music#

[5] http://www.kanzaki.com/ns/music#

example, in the classical music world– a concert with the conductor, performers, the whole program, time schedule, etc. The most general class related with a music piece is the `Musical_Unit`, from which all types of performances derived (e.g. an opera performance, a symphony, a movement of the symphony, etc.).

Table 3. Simac music ontology to MPEG-7 OWL ontology mappings

`simac:Artist ⊆ mpeg7:CreatorType`
`simac:name = mpeg7:GivenName`
`simac:Track ⊆ mpeg7:AudioSegmentType`
`simac:title = mpeg7:Title`
`simac:duration = mpeg7:MediaDuration`
`simac:Descriptor = mpeg7:AudioDSType`
`simac:mode = mpeg7:Scale`
`simac:key = mpeg7:Key`
`simac:tempo = mpeg7:Beat`
`simac:meter = mpeg7:Meter`

Decomposition of a musical unit is achieved by defining its sections, and we link it with the MPEG-7 AudioSegment. Finally, there is an Artist class, which all the agents of the performances (director, musician, singer, etc.) are subclass of. Therefore, we link the Artist class with MPEG-7 OWL and, automatically (transitivity property of `rdfs:subClassOf`) all subclasses are linked with the MPEG-7 OWL ontology.

Table 4. Music Vocabulary ontology to MPEG-7 OWL ontology mappings

`music:Music_Unit ⊆ mpeg7:AudioSegmentType`
`music:sections = mpeg7:AudioSegment`
`music:Artist ⊆ mpeg7:CreatorType`
`music:key = mpeg7:Key`
`music:meter = mpeg7:Meter`

Once these mappings are done, all the multimedia assets are integrated into the ontological framework; that is the MPEG-7 OWL linked with all the schemas. Now, querying the system for audio segments will retrieve information from all the different sources, transparently to the user.

4.2 Semantic Retrieval

Retrieving multimedia assets in the proposed architecture can be easily achieved by using semantic query languages like RDF Query Language (RDQL) [21]. RDQL can take profit from the implicit semantics. It can, as well, exploiting the results of semantic rules for metadata integration in order to retrieve all the related multimedia information for a given query. In our case, RDQL queries use the MPEG-7 OWL ontology "vocabulary" in order to integrate all data source. Using the mappings explained in the previous section, an RDQL query can acquire information from MusicBrainz, Simac, the classical music ontology, etc.

A typical scenario that shows the usefulness of the architecture proposed could be the following: an Internet crawler is looking for audio data (let's assume that is searching for MP3 files) and it downloads all the files. Getting editorial and related information for these audio files can be achieved reading the information stored in the ID3 tag. Unfortunately, sometimes there is no basic editorial information like the title of the track, or the performer.

However, content-based low-level descriptors can be computed for these files, including its MusicBrainz fingerprint, a string that uniquely identifies each audio file based on its content. Improvements on how to calculate a robust fingerprint for an audio file are described in [22]. The next example shows an RDF/N3 description for a track with the calculated tempo and fingerprint:

```
<http://example.org/track#1> a simac:Track;
     simac:tempo “122”;
     musicbrainz:trmid “e3c41bc1-4fdc-4ccd-a471-243a0596518f”.
```

On the other hand, MusicBrainz database has the editorial metadata –as well as the fingerprint already calculated– for more than 3 millions of tracks. For example, the RDF description of the song “Blowin’ in the wind” composed by Bob Dylan:

```
<http://example.org/track#2> a musicbrainz:Track;
     dc:title “Blowin’ in the wind”;
     dc:author [musicbrainz:sortName “Bob Dylan”];
     musicbrainz:trmid “e3c41bc1-4fdc-4ccd-a471-243a0596518f”.
```

A closer look to both examples should highlight that the two resources are sharing the same MusicBrainz’s fingerprint. Therefore, it is clear that, using a simple rule (1), one can assert that both audio files are actually the same file, that is to say the same instance in terms of OWL, owl:sameIndividualAs.

```
mpeg7:AudioType(track1) ∧ mpeg7:AudioType(track2) ∧
musicbrainz:trmid(track1, trm1) ∧
musicbrainz:trmid(track2, trm2) ∧  (trm1 = trm2)
⇒ owl:sameIndividualAs (track1, track2)
```

(**1**)

From now on, we have merged the metadata from both sources and we have deduced that the metadata related with both tracks is, actually, referred to the same track. This data integration (at the instance level) is very powerful as it can combine and merge context-based data (editorial, cultural, etc.) with content-based data (extracted from the audio itself).

Finally, doing an RDQL query that searches for all the songs composed by Bob Dylan that have a fast tempo, retrieves a list of songs, including “Blowin’ in the wind”. Moreover, there is no need for metadata provenance awareness at the end-user level. As the next example shows, all query terms are referred only to the MPEG-7 ontology namespace:

```
SELECT ?title
WHERE (?track,<rdf:type>,mpg7:AudioSegmentType),
      (?track,<mpeg7:Title>,?title),(?track,<mpeg7:Creator>,?author),
      (?author,<mpeg7:Name>,“Bob Dylan”),(?track,<mpeg7:Beat>,?tempo)
AND (?tempo >= 120)
USING mpeg7 FOR
      <http://rhizomik.upf.edu/ontologies/2005/03/Mpeg7-2001.owl#>
```

5 Conclusions and future work

This research work has been guided by the need for a semantic multimedia metadata framework that facilitates multimedia applications development. It has been detected, as it is widely documented in the bibliography, that MPEG-7 is the greatest metadata framework created to date. MPEG-7 is based on XML Schemas and thus its metadata does not have a formal semantics. Consequently, there have been a lot attempts to move MPEG-7 to the Semantic Web.

Our approach is also in this direction, and contributes a complete and automatic mapping of the whole MPEG-7 standard to OWL. It is based on a generic XML Schema to OWL mapping. This mapping has generated our MPEG-7 OWL ontology composed of 2372 classes and 975 properties. It is important to note that this ontology is OWL-Full because the underlying XML Schema model has elements that might have complex and simple type values, i.e. object and data type in OWL terms.

The previous mapping is complemented with an XML metadata instances to RDF mapping that completes a transparent transfer of metadata from the XML to the Semantic Web domain. Once in a semantic space, data integration, which is a crucial factor when several sources of information are available, is facilitated enormously.

We have used the MPEG-7 OWL ontology as an upper-level multimedia ontology where three different music schemas have been linked. Thus, it is possible to retrieve related information from instances of all the sources. Furthermore, detecting and merging instances from different sources has allowed us to enhance the description of audio files, both content-based and editorial data.

High-level descriptors facilitate more accurate content retrieval. Thus, going one step beyond, it would be desirable to combine low-level metadata with as much context-based metadata as possible. From this combination, more sophisticated inferences and rules would be possible. These rules derive hidden high-level metadata that could be, then, easily understandable by the end-user. As an outline of our future plans, (2) shows a rule that extracts a high-level descriptor from low-level descriptors resulting from audio signal processing.

```
mpeg7:AudioType(track) ∧ mpeg7:Beat(track, t) ∧
(t > 120) ∧ mpeg7:Loudness(track, l) ∧ (l > 0.9) ∧
genres:Rock(track)
⇒ danceability(track, “high”)
```

(2)

6 Acknowledgements

Òscar Celma acknowledges the support from SIMAC IST-FP6-507142 European project and Roberto García that from Agent Web TIC 2002-01336 Spanish Administration project and VISNET European Commission IST FP6 Network of Excellence.

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