# Interoperability support for Ontology-based Video Retrieval Applications

Chrisa Tsinaraki, Panagiotis Polydoros, Stavros Christodoulakis

Technical University of Crete, Laboratory of Distributed Multimedia Information Systems and Applications (TUC/MUSIC), University Campus, 73100 Kounoupidiana, Crete, Greece
{chrisa, panpolyd, stavros}@ced.tuc.gr

**Abstract.** Domain ontologies are very useful for indexing, query specification, retrieval and filtering, user interfaces, even information extraction from audiovisual material. The dominant emerging language standard for the description of domain ontologies is OWL. We describe here a methodology and software that we have developed for the interoperability of OWL with the complete MPEG-7 MDS so that domain ontologies described in OWL can be transparently integrated with the MPEG-7 MDS metadata. This allows applications that recognize and use the MPEG-7 MDS constructs to make use of domain ontologies for applications like indexing, retrieval, filtering etc. resulting in more effective user retrieval and interaction with audiovisual material.

## 1. Introduction

The advent of the Internet and the digital multimedia demonstrated the extreme importance of standards for the industry. While in closed environments bound by the organizational walls the organizations could be content with their own software and hardware, in open environments where contact with remote companies or users via Internet or satellite links is of great importance, interoperability through the use of industry standards has become crucial.

In the multimedia industry the MPEG standards have lead the industrial efforts. MPEG-7 [9] [7] is today a very well accepted standard for describing aspects of the multimedia content related to retrieval and filtering, like content structuring metadata, user filtering metadata, usage metadata, segmentation metadata etc. Future work in this area will have to be based on the existing MPEG-7 standard, extending it in appropriate ways.

Retrieval and filtering of audiovisual data is a very important but difficult subject of research for the academia and the industry, and has received a lot of attention in scientific publications [12] [13] [14] [15] [16] [17]. It has been shown in many real-world applications that the retrieval effectiveness (as measured by the precision-recall curves for example) can be greatly improved when domain knowledge encoded in domain ontologies can be used for indexing and retrieval purposes. Since this is also true for audiovisual data, we have developed a methodology for extending the MPEG-7 content metadata with domain knowledge so that we improve the indexing and retrieval of audiovisual content [17]. The extension of MPEG-7 content metadata with domain ontologies is done in a way that is transparent to the applications that only understand MPEG-7 so that they can still be operational, and also take advantage of the domain-specific extensions.

Domain ontologies are often described in domain ontology languages that allow rich ontology structures. OWL [4] is the dominant effort in the standardization of ontology languages and it is expected that both, many domain ontologies will exist in the future described in OWL, as well as that many scientists will be familiar with OWL and will be using it for the definition of new ontologies. It is therefore very important for the audiovisual industry to have a methodology for the interoperability of OWL with MPEG-7 and for the integration of domain ontologies expressed in OWL with MPEG-7.

In this paper we present a methodology and a software implementation that achieves the interoperability of the complete MPEG-7 MDS (including content metadata, filtering metadata etc.) with OWL. We also demonstrate how domain ontologies described in OWL can be integrated in the MPEG-7 MDS in a way that is transparent to the applications that understand MPEG-7. Finally we demonstrate how the domain ontologies that are integrated in various parts of the MPEG-7 MDS can be used to increase the retrieval effectiveness of queries, as well as the retrieval effectiveness of the filtering process using the MPEG-7 user profiles.

The work described in this paper is in the context of the DS-MIRF framework for semantic retrieval of audiovisual metadata, and extends our previous work described in [13] [16] [17] to cover all the aspects of the MPEG-7 MDS. Little has been published in the past in this area of research although the importance of domain ontologies in content recognition, indexing and retrieval is widely recognized [1] [2] [6] [10] [11] [12]. The work that is closest to ours is [5], where the RDF [8] ontology definition language is used to partially describe the MPEG-7 content metadata structures, but not the complete MPEG-7 MDS. This work [5] does not propose a specific methodology and/or software for the integration of domain-specific ontologies in MPEG-7.

Our approach is based on the definition of an OWL Upper Ontology, which fully captures the MPEG-7 MDS. The Upper Ontology is the basis for interoperability between OWL and the MPEG-7 MDS. We also define a methodology for the definition of domain ontologies based on the Upper Ontology. Finally we defined a set of transformation rules that map the domain ontologies that have been described in OWL to the MPEG-7 MDS in a way transparent to the applications of the MPEG-7 MDS.

The rest of the paper is organized as follows: The Upper Ontology capturing the MPEG-7 MDS is presented in section 2, while the applicability of our approach and the benefits of its usage in MPEG-7 applications are presented in section 3. Conclusions and future work are discussed in section 4.

## 2. An Upper Ontology capturing the MPEG-7 MDS

Our approach for interoperability support in multimedia content service provision environments utilizes an ontology that captures the metadata model provided by the MPEG-7 MDS. This ontology, referred as the *Upper Ontology* in the rest of the paper, has been implemented in OWL and is described in this section. We provide an overview of the MPEG-7 MDS in subsection 2.1. The methodology for the Upper Ontology definition is discussed in subsection 2.2.

### 2.1. Overview of the MPEG-7 MDS

We provide in this subsection a brief overview of the MPEG-7 MDS, which provides all the constructs needed for defining metadata that describe the multimedia content and the associated multimedia content services.

Each of the major components of the MPEG-7 MDS is composed of a set of *Description Schemes (DSs)*, essentially complex datatypes, used for the description of concepts in its scope. The MPEG-7 MDS is comprised of the following major components:

- *Basic Elements*, where the basic MDS elements are defined. Basic elements include schema tools (root element, top-level element and packages), basic datatypes, mathematical structures, linking and media localization tools as well as basic DSs, which are used as elementary components of more complex DSs.
- *Content Description & Management Elements*, which are used for the description of the content of a single multimedia document from several viewpoints. Information related to the content management is structured according to the *Creation & Production*, *Media* and *Usage* tools, while information related to the content description is structured according to the *Structural Aspects* and *Semantic Aspects* tools. These two sets of description mechanisms are interrelated.
- *Navigation & Access Elements*, where browsing is supported through multimedia content summary descriptions including information about possible variations of the content. Multimedia content variations can replace the original, if necessary, in order to adapt different multimedia presentations to the capabilities of the client terminals, network conditions, or user preferences.
- *Content Organization Elements*, where the organization of the multimedia content is addressed by classification, by modeling and by the definition of multimedia document collections.
- *User Interaction Elements*, which are used to describe user preferences regarding multimedia content, as well as material consumption aspects.

The MPEG-7 MDS has been defined by the standardization body using the MPEG-7 DDL, which is essentially based on the XML Schema Language [3], extended with the definition of the basic datatypes needed for the definition of the complex DSs of the MPEG-7 MDS.

## 2.2. Upper Ontology Definition Methodology

We describe in this subsection the methodology that we developed and applied for the definition of the OWL Upper ontology that fully captures the concepts of the MPEG-7 MDS. The Upper Ontology was defined according to the following methodological steps:

1. *MPEG-7 Simple Datatype Representation:* OWL does not provide mechanisms for simple datatype definition, but it permits the integration of simple datatypes defined in the XML Schema Language using the rdfs:Datatype construct. Thus, we store all the definitions of the simple datatypes of the MPEG-7 MDS in an XML schema file, represented by the &datatypes; XML entity. In addition, an rdfs:Datatype instance is defined in each of the ontology definition files for every simple datatype used in it. For example, in order to use the "zeroToOneType" datatype shown in **Fig. 1**, which represents real numbers between 0 and 1, we define the rdfs:Datatype instance of **Fig. 2** in order to use the "zeroToOneType" type (defined in XML Schema) in the Upper Ontology.

```
<simpleType name="zeroToOneType">
  <restriction base="float">
    <minInclusive value="0.0"/>
    <maxInclusive value="1.0"/>
  </restriction>
</simpleType>
```

**Fig. 1.** Definition of the zeroToOneType datatype in the MPEG-7 MDS

```
<rdfs:Datatype rdf:about="&datatypes;zeroToOneType">
  <rdfs:isDefinedBy rdf:resource="&datatypes;"/>
  <rdfs:label>zeroToOneType</rdfs:label>
</rdfs:Datatype>
```

**Fig. 2.** Definition of the rdfs:Datatype instance for the zeroToOneType datatype

Then, if there is a property of "zeroToOneType" type, which belongs to one of the Upper Ontology classes, the property type is denoted in the rdfs:range element of the property, as shown in **Fig. 3**.

```
<rdfs:range rdf:resource="&datatypes;zeroToOneType"/>
```

**Fig. 3.** Definition of a property of zeroToOneType type

2. *MPEG-7 Complex Type Representation:* MPEG-7 complex types correspond to OWL classes, which represent groups of individuals that belong together because they share some properties. Thus, for every complex type defined in the MPEG-7 MDS we define a respective OWL class using the owl:Class construct, having as rdf:ID the value of the complex type name.

   2.1. *Simple Attribute Representation:* The simple attributes of the complex type of the MPEG-7 MDS are represented as OWL datatype properties, which relate class instances to datatype instances (e.g. integer, string etc.). Thus, for every simple attribute of the complex type a datatype property is defined using the owl:DatatypeProperty construct.

2.1.1. The datatype property is "attached" to the OWL class through the rdfs:domain construct, which denotes the domain of the property. The value of the rdfs:domain of the datatype property is the rdf:ID value of the newly-defined class.

2.1.2. The type of the values associated with the class through the datatype property is denoted in the rdfs:range element of the property. If the attribute type is an enumerated type, the owl:DataRange construct is used in the context of rdfs:range.

2.2. *Complex Attribute Representation:* Complex attributes are represented as OWL object properties, which relate class instances. For every complex attribute of the complex type the following actions are performed:

2.2.1. An OWL class for the representation of the complex attribute instances is defined, if it does not already exist.

2.2.2. An OWL object property that relates the complex attribute instances with the complex type instances is defined using the owl:ObjectProperty construct. The domain and the range of the object properties are defined in the same way with the datatype properties.

2.3. *Subclassing:* For the representation of the subclass/superclass relationships holding for the complex type, the following actions are performed:

2.3.1. If the complex type is a subtype of another complex type, the subclass relationship is represented by an instance of the rdfs:subClassOf construct, which relates the newly-defined class its superclass.

2.3.2. If the complex type is a subtype of a simple type, a datatype property with rdf:ID "content" and rdfs:range of the simple type is associated with the newly-defined OWL class.

2.4. *Constraints:* Constraints regarding value, cardinality and type for simple and complex attributes are expressed using the owl:Restriction construct together with the owl:hasValue, owl:cardinality (owl:maxCardinality, owl:minCardinality and owl:FunctionalProperty may also be used) and owl:allValuesFrom constructs. Complex constraints are defined using the boolean operations owl:IntersectionOf, owl:UnionOf and owl:ComplementOf.

As an example, we show in **Fig. 5** the definition of the OWL class "FilteringAndSearchPreferencesType" (subclass of the "DSType" that represents all the Descriptor Schemes), corresponding to the MDS complex type "FilteringAndSearchPreferencesType" shown in **Fig. 4**. The complex attribute "CreationPreferences" and the simple attribute "protected" are also shown in **Fig. 4** and the corresponding "CreationPreferences" object property and the "protected" datatype property are shown in **Fig. 5**.

```
<complexType name="FilteringAndSearchPreferencesType">
  <complexContent>
    <extension base="mpeg7:DSType">
    <sequence>
      <element name="CreationPreferences"
type="CreationPreferencesType" minOccurs="0" maxOccurs="unbounded"/>
    </sequence>
    <attribute name="protected" type="userChoiceType"
use="optional"/>
  </complexContent>
</complexType>
```

**Fig. 4.** The FilteringAndSearchPreferencesType MDS complex type

```
<owl:Class rdf:ID="FilteringAndSearchPreferencesType">
  <rdfs:subClassOf rdf:resource="#DSType"/>
</owl:Class>
<owl:ObjectProperty rdf:ID="CreationPreferences">
  <rdfs:domain rdf:resource="#FilteringAndSearchPreferencesType"/>
  <rdfs:range rdf:resource="#CreationPreferencesType"/>
</owl:ObjectProperty>
<owl:DatatypeProperty rdf:ID="protected">
  <rdfs:domain rdf:resource="#FilteringAndSearchPreferencesType"/>
  <rdfs:range rdf:resource="&datatypes;userChoiceType"/>
  <rdf:type rdf:resource="&owl;FunctionalProperty"/>
</owl:DatatypeProperty>
```

**Fig. 5.** The FilteringAndSearchPreferencesType OWL class

3. *MPEG-7 Relationship Representation:* Relationships between the OWL classes, which correspond to the complex MDS types, are represented by the instances of the "RelationBaseType" class and its subclasses. Every "RelationBaseType" instance is associated with a source and a target metadata item through the homonym object properties.

The complete Upper Ontology has been designed using the above rules but is not shown here due to space limitations. It is an OWL-DL ontology, available at [18], which has been validated by the OWL species ontology validator[1].

## 3. MPEG-7 Application Support

We present in this section the use of our approach for metadata management in multimedia content service environments. Our approach includes, in addition to the Upper Ontology described in the previous section, the integration of OWL domain ontologies (lower ontologies) in order to provide higher quality content services. We focus here in the description of the advantages of our approach in search and filtering services.

In order to verify our design and implementation we have developed a complete domain ontology (lower ontology) for soccer games in OWL and have implemented the software needed for the transformation of OWL/RDF metadata defined using the Upper Ontology and the domain ontologies to MPEG-7 compliant metadata [16]. In addition, we have developed an MPEG-7 compliant API that supports ontology-based retrieval and filtering [13].

We discuss in the next subsections the methodology for domain-specific ontology definition and integration to the Upper Ontology (subsection 3.1) and the retrieval and filtering support provided (subsection 3.2).

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[1] The OWL species validator, available at http://phoebus.cs.man.ac.uk:9999/OWL/Validator, validates OWL ontologies and checks if an ontology conforms to one of the OWL species.

### 3.1. Methodology for the Integration of OWL domain Ontologies

In this subsection we present the methodology for the definition and integration of domain ontologies that extend the semantics encapsulated in the Upper Ontology with domain knowledge.

The domain ontologies comprise the second layer of the semantic metadata model used in the DS-MIRF framework [14] [15], with the first layer of the model encapsulated in the Upper Ontology. Thus, the classes representing the domain-specific entities should be defined in a way that extends the Upper Ontology. Having these in mind, the domain ontologies are defined according to the following methodological steps:

1 Domain-specific entity types are represented by OWL classes that are subclasses of the appropriate Upper Ontology classes. For example, in a football tournament application the "FootballTeam" subclass of the "OrganizationType" Upper Ontology class, is used for the representation of football teams as is shown in **Fig. 6**.

```
<owl:Class rdf:ID="FootballTeam">
  <rdfs:subClassOf rdf:resource="#OrganizationType"/>
</owl:Class>
```

**Fig. 6.** OWL Definition the FootballTeam class

1.1 Attributes (both simple and complex) not present in the superclass are represented as appropriate object or datatype properties.

1.2 Additional constraints may be applied on the attributes inherited from the parent class, in order to guide the indexers to produce valid metadata.

2 Relationships with additional restrictions compared with the ones of the general relationships defined in the Upper Ontology are usually needed (e.g. a Goal event may be related to player instances as goal agents). In these cases, appropriate subclasses of "RelationBaseType" or of its appropriate subclass are defined and all the restrictions needed are applied to the newly defined classes.

A more detailed discussion on this methodology and its application for the description of the semantics of soccer games can be found in [16].

### 3.2. Search and Filtering Support

We present in this subsection the advantages of our approach in search and filtering services. The retrieval and filtering support is based on the query API developed in the context of the DS-MIRF framework [13].

The end-users may now pose semantic queries on the semantics of the audiovisual content using transparently the API functions through the appropriate interface. The queries may be based on the general constructs provided by MPEG-7 (queries 1, 5 and 6 of **Table 1**) or on the domain knowledge (queries 2, 3 and 4). Such queries are shown in **Table 1**, where we assume that the ID of the person named "Ronaldo" is P1 and the ID of the person named "Kahn" is P2. We also assume that the ID of the soccer stadium named "Old Trafford" is SP1, the ID of Europe is SP2 and the ID of the date 1/1/2003 is ST1. It is obvious from the examples that the queries that make use of the domain knowledge are more expressive than the more general ones and their results will be better in terms of precision/recall.

| Query | Description in Free Text |
| --- | --- |
| 1. `GetSegment(P1 Person null)` | "Give me the segments where Ronaldo appears" (not only as a player!) |
| 2. `GetSegmentMQT(null Event Goal AND P1 Person Player hasCauserOf)` | "Give me the segments where the player Ronaldo scores" |
| 3. `GetSegmentMQT(null Event Goal AND (P1 Person Player hasCauserOf) (P2 Person Player hasPatientOf))` | "Give me the segments where the player Ronaldo scores against the player Kahn" |
| 4. `GetSegmentMQT(null Event Goal AND (ST1 SemanticTime GameTime hasTimeOf) (SP1 SemanticPlace SoccerStadium hasPlaceOf))` | "Give me the segments where a goal takes place in 1/1/2003 in the soccer stadium Old Trafford" |
| 5. `GetSegmentMQT(null SemanticTime null AND ST1 SemanticTime null after)` | "Give me the segments referring to time after 1/1/2003" |
| 6. `GetSegmentMQT(null SemanticPlace null AND SP2 SemanticPlace null inside)` | "Give me the segments where places inside Europe appear" |

**Table 1.** Semantic Query Examples

Our methodology can be used also for enhancing the user profiles with domain-specific filtering preference definitions. Consider now a user who wants to denote in his preference profile that he is interested in watching the extra time of soccer games. This can be achieved when he sets his preference conditions regarding soccer games. If domain knowledge has not been encapsulated in the application he uses, he can approximately specify the time point that the extra time (overtime) begins and the corresponding end time point (relative to the game start). In this case, if we assume that the ID of the approximate start time point is STP1 and the ID of the approximate end time point is STP2, the API query used (transparently to him) for the retrieval of the corresponding video segment is the query shown in **Fig. 7**. It is obvious that the audiovisual segment returned to him may contain events before or after the extra time and that not all the extra time duration may be retrieved (e.g. because of a delay) if there was extra time given for the game. If there was no extra time given, an audiovisual segment with irrelevant content should be returned.

```
GetSegmentMQT(null SemanticTime null AND STP1 SemanticTime null after
AND STP2 SemanticTime null before)
```

**Fig. 7.** Query for the approximate retrieval of the segment containing the extra time of a soccer game

If there exists domain knowledge, only if there was extra time given for the game the appropriate segment will be returned. The API query used, transparently to the user, is the one shown in **Fig. 8**.

```
GetSegment(null SemanticTime ExtraTime)
```

**Fig. 8.** Query for the retrieval of the segment containing the extra time of a soccer game

## 4. Conclusions – Future Work

In this paper we have presented a methodology for interoperability support between MPEG-7 and OWL, based on an OWL Upper Ontology that fully captures the semantics of the MPEG-7 MDS. The integration of domain specific knowledge in multimedia content applications is done through the extension of the Upper Ontology with OWL domain ontologies (lower ontologies). We have described the Upper Ontology definition methodology, as well as a methodology for the definition of domain ontologies that extend the Upper Ontology, in order to fully describe the concepts of specific application domains in a manner transparent to MPEG-7 applications. The complete OWL Upper Ontology describing the MPEG-7 MDS is available in [18]. In addition, we have presented the use of our approach in search and filtering services. The usage of the approach was presented through its application in MPEG-7-based multimedia content services.

Our future research in the area includes:

- The complete development of the *MOREL (Multimedia, Ontology-based REtrieval Language)* language based on the existing query API. The MOREL language aims to support queries that make use of ontologies in multimedia content service environments.
- The application of our approach (utilization of the Upper Ontology and of domain ontologies extending it) in applications from all aspects covered by the MPEG-7 MDS (user preferences, summarization etc.) in addition to applications for the semantic description of audiovisual content.

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