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Richard Arndt
Steffen Staab
Raphaël Troncy
Lynda Hardman

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Universität Koblenz-Landau • Campus Koblenz • Universitätsstraße 1 • 56070 Koblenz
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Richard Arndt, Steffen Staab
Raphaël Troncy, Lynda Hardman
Institut für Informatik
Fachbereich Informatik
Universität Koblenz-Landau
Universitätsstraße 1
D-56070 Koblenz
EMail: rarndt@uni-koblenz.de; staab@uni-koblenz.de

Adding Formal Semantics to MPEG-7: Designing a Well-Founded Multimedia Ontology for the Web

Richard Arndt
ISWeb, University of Koblenz-Landau
Germany
rarndt@uni-koblenz.de

Raphaël Troncy
CWI, Amsterdam
The Netherlands
Raphael.Troncy@cwi.nl

Steffen Staab
ISWeb, University of Koblenz-Landau
Germany
staab@uni-koblenz.de

Lynda Hardman[*]
CWI, Amsterdam
The Netherlands
Lynda.Hardman@cwi.nl

ABSTRACT

Semantic descriptions of non-textual media available on the web can be used to facilitate retrieval and presentation of media assets and documents containing them. While technologies for multimedia semantic descriptions already exist, there is as yet no formal description of a high quality multimedia ontology that is compatible with existing (semantic) web technologies. We explain the complexity of the problem using an annotation scenario. We then derive a number of requirements for specifying a formal multimedia ontology, including: compatibility with MPEG-7, embedding in foundational ontologies, and modularisation including separation of document structure from domain knowledge. We then present the developed ontology and discuss it with respect to our requirements.

Categories and Subject Descriptors

H.4.m [**Information Systems**]: Miscellaneous; I.7.2 [**Document Preparation**]: Languages and systems, Markup languages, Multi/mixed media, Standards; I.2.4 [**Knowledge Representation Formalisms and Methods**]: Representation languages

General Terms

Languages, Standardization

Keywords

Multimedia Ontology, MPEG-7, DOLCE, Model

1. INTRODUCTION

Multimedia objects on the Web are omnipresent as they are delivered from dedicated producers like media and publishing houses or from IP-TV broadcasts, but also from the broad public itself (e.g. via Flickr[1] or YouTube[2]). All multimedia clientele, producers and consumers alike, however, has difficulties in organizing, finding, retrieving and accessing the 'right' media objects, although dedicated applications for multimedia processing and understanding, such as temporal and spatial multimedia object segmentation, scene classification, face recognition, person discovery, or manual annotation and tagging approaches using ontologies or folksonomies constitute an established state-of-the-art.

As we will show in this paper, reasons for this problem stem from a lack of interoperability in this manifold of multimedia processing and understanding applications. Individual annotation and tagging applications have so far not achieved a degree of interoperability that would enable effective sharing of semantic metadata and that would link the metadata to semantic data and ontologies found in the Semantic Web.

MPEG-7 is an international standard developed to address this issue. In particular, it specifies how to connect descriptions to parts of a media asset. The standard includes descriptions of low-level media-specific features that can often be automatically extracted from media types. Unfortunately, MPEG-7 is not currently suitable for describing multimedia content on the Web, because *i)* its XML Schema-based nature prevents the effective manipulation of descriptions and its use of URNs is cumbersome for the web; *ii)* it is not open to the Web standards for representing knowledge and that make use of existing controlled vocabularies.

While technologies such as MPEG-7 for multimedia semantic descriptions already exist, there is as yet no formal description of a multimedia ontology that is compatible with existing (semantic) web technologies. The web, on the other hand, has no agreed-upon means of describing and connecting semantics with (parts of) multimedia assets and documents. Our contribution is thus to combine the advantages of the extensibility and scalability of web-based solutions with the accumulated experience of existing multimedia ontologies, such as MPEG-7. Our approach advocates the use of formal semantics, grounded in a sound ontology development methodology, to describe the required multimedia semantics in terms of current semantic web languages.

In the next section, we illustrate the main problems when using MPEG-7 for describing multimedia resources on the web. In section 3, we derive from this example the require-

[*]Lynda Hardman is also affiliated with the Technical University of Eindhoven.
[1]http://www.flickr.com/
[2]http://www.youtube.com/

ments for designing a well-founded multimedia ontology, and we show why the proposals made so far are inadequate. In section 4, we detail our proposal – an MPEG-7 based ontology, designed using sound formal design principles – and discuss our design decisions based on our requirements. In section 5, we demonstrate the use of the ontology with the scenario from section 2 and then conclude with some observations and future work.

2. ANNOTATING MULTIMEDIA DOCUMENTS ON THE WEB USING MPEG-7

Let us imagine that Martin, a student of semiotics in art[3], would like to annotate the image depicting the painting *The Treachery Of Images* of René Magritte (Fig. 1) on the (semantic) web.

The picture shows a pipe that looks as though it might come from a tobacco store advertisement. Magritte painted below the pipe **Ceci n'est pas une pipe (This is not a pipe)**, which seems a contradiction, but is actually true: the painting is not a pipe; it is an image of a pipe. As Magritte himself commented: "*Just try to stuff it with tobacco! So if I had written on my picture 'This is a pipe' I would have been lying.*". This painting and its paradox illustrates perfectly the duality of describing an object or a scene and an image or a video depicting or representing this object or scene [14, 16].

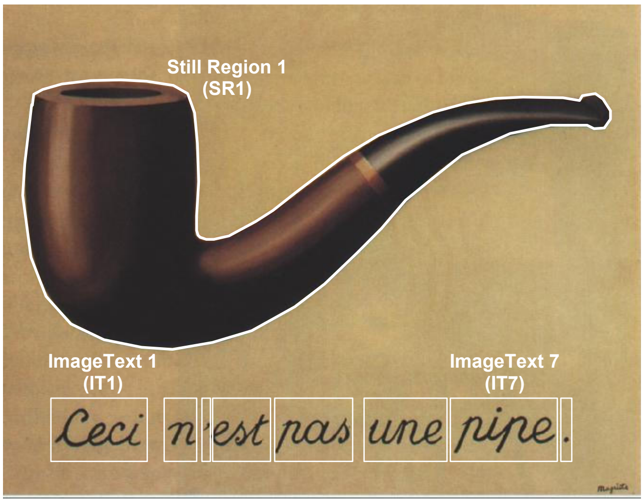

Figure 1: René Magritte, *The Treachery Of Images*. Image adapted from Wikipedia

When annotating this image, Martin has to cope with several problems:

Fragment identification. He first localizes particular regions of the image: the *pipe* object and the provocative textual caption split into eight rectangular regions. However, the current web architecture does not provide a means for uniquely identifying sub-parts of multimedia documents, in the same way that the fragment identifier in the URI can refer to part of an HTML or XML document. Actually, for almost all other media types, the semantics of the fragment identifier has not be defined or is not commonly accepted. Providing an agreed upon way to localize sub-parts of multimedia objects (e.g. sub-regions of images, temporal sequences of videos or tracking moving objects in space and in time) is fundamental [5]. For images, one can use either MPEG-7 or SVG snippet code to define the bounding box coordinates of specific regions. But this approach requires an indirection: an annotation would *be about* a fragment of a XML document that *refers* to a multimedia document. For temporal location, one can use again the MPEG-7 code with the same limitation, or use the forthcoming TemporalURI RFC standard [19], which does not have this limitation.

Semantic annotation. Martin then describes the painting: MPEG-7 is a natural candidate for representing his annotations. The language, standardized in 2001, specifies a rich vocabulary of multimedia description tools[4] which can be represented in either XML or a binary format. While it is possible to specify very detailed annotations using the description tools, it is not possible to guarantee that MPEG-7 metadata generated by different agents will be mutually understood due to the lack of formal semantics of this language [6, 23]. The XML code of Fig. 2 illustrates the inherent interoperability problems of MPEG-7 [24]: several description tools, semantically equivalent and representing the same information can coexist[5]. For example, Martin experimented with two different, MPEG-7 compliant, optical character recognition (OCR) applications to recognize the segmented words. While the first one makes use of the `<Text>` element of the `ImageTextType` (region `IT1`), the second one uses the `<StructuredAnnotation>` element for attaching the same kind of information (region `IT7`). Moreover, Martin has manually described the pipe object with a keyword (region `SR1`). Consequently, a query for all still regions that feature a `<TextAnnotation>` with the value "pipe" would return both the regions `SR1` and `IT7`, which might not be the intended result. On the other hand, the alternative ways for annotating the two text segments `IT1` and `IT7` complicate the retrieval of all text portions within images, since the corresponding XPath query has to deal with these syntactic variations.

Web interoperability. Finally, Martin would like to link his annotations to both the creative commons rights of the image he found on the web and to the metadata of this painting provided by the Los Angeles County Museum of Art[6] (LACMA) in Los Angeles, California. This (possibly RDF) metadata[7] gives information about the dimensions of the paintings and the technique the Belgian artist used (oil on canvas). Martin has also found ontologies on the web that distinguish an object from a piece of text, and that formally define what a pipe is. However, he realizes that MPEG-7 cannot be combined with these concepts defined in domain-specific ontologies because of its incompatibility with the web.

As these examples demonstrate, though MPEG-7 provides ways of associating semantics with (parts of) non-textual media assets, it is incompatible with (semantic) web tech-

[3] Martin Lefebvre is a student from the University Paris 1, Panthéon-Sorbonne, who has analyzed some paintings of Magritte, `http://imagesanalyses.univ-paris1.fr/`.

[4] A good overview of MPEG-7 can be found in [12, 13].

[5] See also `http://www.w3.org/2005/Incubator/mmsem/wiki/MPEG-7_metadata_interoperability_Use_case`.

[6] `http://www.lacma.org/`

[7] `http://collectionsonline.lacma.org/mwebcgi/mweb.exe?request=record&id=34438&type=101`

```
<Mpeg7>
 <Description xsi:type="ContentEntityType">
  <MultimediaContent xsi:type="ImageType">
   <Image>
    <SpatialDecomposition>
     <StillRegion id="SR1">
      <TextAnnotation>     <!-- TextAnnotationType -->
       <KeywordAnnotation xml:lang="fr">
        <Keyword> pipe </Keyword>
       </KeywordAnnotation>
      </TextAnnotation>
     </StillRegion>
     <StillRegion id="IT1" xsi:type="ImageTextType">
      <Text xml:lang="fr"> Ceci </Text>
     </StillRegion>
     ...
     <StillRegion id="IT7" xsi:type="ImageTextType">
      <Semantic>
       <Definition>   <!-- Also TextAnnotationType -->
        <StructuredAnnotation>
         <WhatObject>
          <Name xml:lang="fr"> pipe </Name>
         </WhatObject>
        </StructuredAnnotation>
       </Definition>
      </Semantic>
     </StillRegion>
     ...
```

Figure 2: MPEG-7 annotation example of Fig. 1

nologies and has no formal description of the semantics encapsulated implicitly in the standard.

3. RELATED WORK

These, and other, drawbacks of MPEG-7 have already been reported [14, 16, 23, 25]. In the field of semantic image understanding, using a multimedia ontology infrastructure is regarded to be the first step for closing the, so-called, semantic gap [22] between low-level signal processing results and explicit semantic descriptions of the concepts depicted in images. Furthermore, multimedia ontologies have the potential to increase the interoperability of applications producing and consuming multimedia annotations. As a solution to the drawbacks of MPEG-7, multimedia ontologies based on the standard have been proposed [4, 6, 9, 26]. The problem with these proposals, however, is that they do not fully capture the intended semantics of the MPEG-7 standard.

Rather than continue with similar approaches, we take a step back and first consider the problems underlying the development of a multimedia ontology. We first review existing multimedia ontologies (section 3.1), define the requirements that a multimedia ontology should meet (section 3.2), and then discuss key design decisions (section 3.3).

3.1 Review of Existing Multimedia Ontologies

Hunter [6] provided the first attempt to model parts of MPEG-7 into RDFS, later converted into DAML+OIL. This ontology covers the upper part of MPEG-7 and has been integrated with the ABC model [7] to make an OWL Full ontology. Tsinaraki et al. [26] start from the core of this ontology and extend it to cover the full Multimedia Description Scheme (MDS) part of MPEG-7, in an OWL DL ontology. The result is decoupled from the ABC model, but special emphasis is put on linking domain specific knowledge with the multimedia ontology. A complementary approach was explored by Isaac and Troncy [9], who proposed a core audio-visual ontology inspired by several terminologies, either standardized (such as MPEG-7 and TV Anytime[8]) or still under development (ProgramGuideML). Garcia and Celma [4] produced the first complete MPEG-7 ontology by automatically generating a generic mapping from XSD to OWL. The definitions of the XML Schema types and elements of MPEG-7 are converted into OWL Full axioms. Finally, Simou et al. proposed an OWL DL Visual Descriptor Ontology[9] (VDO) based on the visual part of MPEG-7 and used for image and video analysis.

All these methods perform a one to one translation of MPEG-7 types into OWL concepts and properties. This translation does not, however, guarantee that the intended semantics of MPEG-7 is fully captured and formalized. On the contrary, the syntactic interoperability and conceptual ambiguity problems illustrated in section 2 remain. The problem is even exacerbated, since a one to one translation results in different formal terms that express semantically identical concepts. Hunter [7] and Tsinaraki et al. [26] have highlighted that MPEG-7 provides a closed set of descriptors, which, while indeed very rich, cannot be augmented. A one to one translation also retains this closed model and prevents linking to existing knowledge represented on the (semantic) web.

3.2 Requirements for a Multimedia Ontology

Requirements for designing a multimedia ontology [1, 8, 25] as well as characteristics of badly modeled ontologies [15] have been gathered and reported in the literature. Here, we compile these and present a list of requirements for a web-compliant multimedia ontology.

MPEG-7 compliance. MPEG-7 is an existing international standard, used both in the signal processing and the broadcasting communities. It contains a wealth of accumulated experience which needs to be included in a web-based ontology. In addition, existing annotations in MPEG-7 should be easily convertible to our ontology. In particular, existing MPEG-7 description tools should be directly expressible.

Semantic interoperability. Annotations are only reusable when the captured semantics can be shared among multiple systems and applications. A semantic interoperability problem is illustrated in the example in section 2, where the term "pipe" needed to be explicitly defined. Obtaining similar results from reasoning processes about terms in different environments can only be guaranteed if the semantics is sufficiently explicitly described. A multimedia ontology has to ensure that the intended meaning of the captured semantics can be shared among different systems.

Syntactic interoperability. Systems are only able to share the semantics of annotations if there is a means of conveying this in some agreed-upon syntax. The (semantic) web is an important repository of both media assets and annotations. Any semantic description of the multimedia ontology should be expressible in a web language.

Separation of concerns. Clear separation of domain knowledge (i.e. knowledge about depicted entities, such as a "pipe") from knowledge that is related to the administrative management or the structure and the features of multimedia documents (e.g. the picture is above the text) is required. Reusability of multimedia annotations can only be achieved

[8] http://www.tv-anytime.org
[9] http://image.ece.ntua.gr/~gstoil/VDO

if the connection between both ontologies is clearly specified by the multimedia ontology [5].

Modularity. A complete multimedia ontology can be, as demonstrated by MPEG-7, very large. This forces the whole schema (several thousands of XML elements) to be included, even though only a small part may be useful for a given application [25]. The design of a multimedia ontology should thus be made modular, to minimize the execution overhead when used for multimedia annotation.

Extensibility. While we intend to construct a comprehensive multimedia ontology, as ontology development methodologies demonstrate, this can never be the case. New concepts will always need to be added to the ontology. This implies a design that can always be extended, without changing the underlying model and assumptions and without affecting legacy annotations.

3.3 Design Discussion

Much of the earlier work on multimedia ontology development was heavily influenced by MPEG-7, since it represents a large amount of accumulated knowledge from the multimedia analysis community. In addition, it specifies the connection between semantic annotations and parts of media assets. Another advantage of MPEG-7 is that it already has users, e.g. from the broadcasting community. As such, while we do not advocate a one to one mapping from MPEG-7 to a web knowledge representation language, we do take it as a base of knowledge that needs to be expressible in our ontology. Therefore, we decided on re engineering MPEG-7 according to the intended semantics of the written standard without aligning our ontology to the XML Schema definition of MPEG-7.

Our most important requirement, after the specification of the semantics we wish to express, is that of providing semantic interoperability. We satisfy this by providing a formal semantics for MPEG-7. This requires the development of a multimedia ontology, for which we use a methodology proposed by Oberle et al. [15]. They advocate the use of a foundational, or top level, ontology as a basis for designing several core ontologies. They argue that the design benefits from a grounding in a foundational ontology because it provides a general and domain independent vocabulary that explicitly includes formal definitions of foundational categories, such as processes or physical objects. Using a foundational ontology also eases the linkage of domain-specific ontologies because of the general definition of the top level concepts. Well-founded ontologies should thus be more easily extensible, modular and highly interoperable.

Oberle et al. [15] also specify a number of other requirements which we take into account, namely:

Conceptual Clarity. The meaning of the concepts and their relations should be clearly described and easily understood. This reduces the chance of conceptually ambiguous descriptions.

Rich Axiomatization. The intended semantics of all ontological concepts should be formally expressed by defining restrictions on them.

Precise Design. All modeling artifacts specified in the axiomatization should carry ontological meaning.

Broad Scope. The ontology should include a broad scope of concepts to ensure accuracy and completeness and allow for later extensibility.

Our final decision is which language to use to express the ontology. We choose OWL DL [17], since this is developed specifically for the Web, is sufficiently expressive for our purposes and avoids the computational complexities of OWL Full. OWL DL has itself a formally defined semantics and ontologies expressed in OWL can naturally be linked to existing (RDF) metadata on the web, thus satisfying our semantic and syntactic interoperability requirements.

4. ADDING FORMAL SEMANTICS TO MPEG-7

In order to satisfy our stated requirements, we choose to express the semantics already present in MPEG-7 in a well-founded multimedia ontology. To create a core ontology, based on an existing foundational ontology, we need to select a suitable candidate. We discuss our chosen foundational ontology in section 4.1, and then present our multimedia ontology in sections 4.2 and 4.3. Finally, we discuss why our ontology satisfies all our stated requirements in section 4.4.

Our MPEG-7 based multimedia ontology is available at `http://multimedia.semanticweb.org/ontology/`.

4.1 DOLCE as Modeling Basis

Oberle et al. [15] review existing foundational ontologies and provide several criteria for comparing them. We consider the Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) [10] to be best suited as a modeling basis for a multimedia ontology. Of vital importance for this preference are the design patterns for *Descriptions & Situations* (D&S) and *Ontology of Information Objects* (OIO), which are two of the main patterns provided by DOLCE. The former pattern can be used to formalize contexts, while the latter, based on D&S, implements a semiotics model of communication theory. As our multimedia ontology is entirely based on these two design patterns, we briefly present them here. A complete description of these patterns can be found in [2, 3] where they are introduced as abstract design patterns, applicable on top of arbitrary foundational ontologies providing similar concepts to the ones of DOLCE. We refer the reader to [10] for a detailed description of the top-level ontology DOLCE itself.

4.1.1 Descriptions & Situations

The main structure of the D&S design pattern is shown in Fig. 3 as an UML diagram. It provides a means of express-

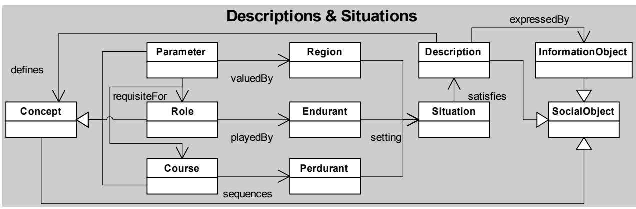

Figure 3: Descriptions & Situations Pattern

ing contextual knowledge, which is fundamental for multimedia. An example of context that can be expressed using D&S is the different perspective on image data which can play the role of input or output in different stages of image analysis. D&S formalizes context by defining the relationship between Situations[10] and their Descriptions. Using the D&S extension implies that the basic DOLCE concepts, i.e. Region[11], Endurant[12] and Perdurant[13], are regarded as ground entities. Their instances serve as settings for Situations. D&S introduces three descriptive concepts, i.e. Parameter, Role and Course which are defined by Descriptions and are used to state the meaning of the DOLCE basic concepts within a Situation. Parameters are valued by Regions, Roles are played by Endurants and Courses are sequenced by Perdurants. These descriptive concepts are defined by Descriptions which represent the context of Situations. The link between Descriptions and Situations is defined by the satisfies relationship. It holds if a set of entities that are grouped by a Situation via the setting relationship can be described by the rules of a Description.

The description of the workflow for annotating a picture is an example of a Description. It is satisfied by a Situation which represents the work that is being performed. Such a Situation is a setting for a person, e.g. Martin who plays the Role of the user of an application. This application is a setting for the same Situation and plays the Role of an annotation software. Perdurants of this Situation are the processes of loading the image, annotating it and finally saving it. They are all explained by Courses. User preferences of Martin are an example of Parameters which are a requisite for his user Role. The workflow Description defines all mentioned Roles, Courses and Parameters.

4.1.2 *Ontology of Information Objects*

The core of the OIO design pattern is depicted in Fig. 4. It

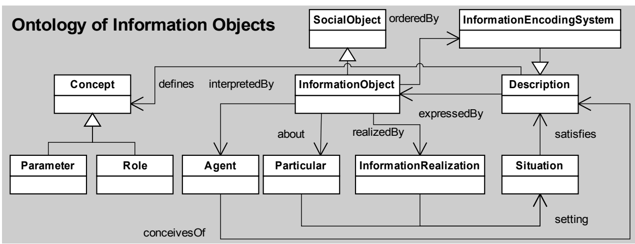

Figure 4: Information Objects Pattern

is built on the D&S pattern which already includes the central InformationObject concept (see Fig. 3). InformationObjects are regarded as “spatio-temporal reifications of pure (abstract) information (as described e.g. in Shannon’s communication theory), hence they are assumed to have an existence over time, and are realized by some entity” [2]. The information contained by an InformationObject is embodied through some facts of which InformationObjects are about. These facts exist within the context (Description) that is expressed by an InformationObject. A physical representation of an InformationObject, is called InformationRealization. InformationObjects are ordered by InformationEncodingSystems. According to communication theory, the OIO pattern also includes Agents which interpret InformationObjects and conceive the Descriptions that are expressed by InformationObjects.

4.2 Multimedia Patterns

The patterns for D&S and OIO cannot be used immediately for representing the MPEG-7 concepts since they are not close enough to the technical domain of multimedia annotation. Therefore, we have modeled several specialized patterns that take into consideration the peculiarities of multimedia. This section introduces these multimedia design patterns, while section 4.3 details two central concepts underlying these patterns: digital data and algorithms.

In order to define design patterns, one has to identify repetitive structures and describe them on an abstract level. In our case, we have identified the two most important functionalities provided by MPEG-7 and highlighted them in the example presented in section 2. A similar analysis can be found in [23].

Decomposition. MPEG-7 provides numerous useful descriptors for describing spatial, temporal, spatio-temporal and media source decompositions of multimedia content into segments. A segment is the most general abstract concept in MPEG-7 and can refer to a still region of an image, a piece of text, a temporal scene of a video or even to a moving object tracked during a period of time.

Annotation. MPEG-7 provides a very large collection of descriptors that can be used to annotate a segment. These descriptors can be low-level visual features, audio features or more abstract concepts. They allow the annotation of the content of multimedia documents, its structure or the media itself. In the last case, a separate formalization is needed to satisfy our separation of concerns requirement (section 3.2). We need to be able to express, for example, an Image (media) that realizes ImageData (multimedia content) has been generated by using JPEG compression and that its file size is 273 KB.

Our proposed multimedia ontology covers these two fundamental functionalities. In the following, we present the patterns that formalize the decomposition of multimedia content into segments (section 4.2.1), or allow content annotation (section 4.2.2) and media annotation (section 4.2.3). Even though MPEG-7 provides some general abstract concepts that can be used to describe the perceivable content of a multimedia segment, independent development of domain-specific ontologies is more appropriate for describing possible interpretations of multimedia — it is useful to create an ontology specific to multimedia, it is not useful to try to model the real world within this. Consequently, we have modeled a semantic annotation design pattern, specializing the content annotation pattern. This allows the connection of multimedia descriptions with domain descriptions provided by independent world ontologies (section 4.2.4). This interface also provides a solution to Martin’s web interoperability problem when he would like to link his annotations to existing metadata of the painting provided by the LACMA museum.

4.2.1 *Decomposition Pattern*

We consider a decomposition of a MultimediaData entity to be a Situation (a SegmentDecomposition) which satisfies a Description such as a SegmentationAlgorithm (an OCR tool recognizing automatically the words of the caption) or a Method (Martin drawing manually a region around the pipe

[10]Sans serif font indicates ontological concepts.

[11]DOLCE Regions must not be mistaken for regions in an image as they represent values of properties, i.e. Qualitys.

[12]Entities which exist in time and space, e.g. a human being.

[13]Events, processes or phenomena are examples for Perdurants. Endurants participate in Perdurants.

object) which has been applied to perform the decomposition, see Fig. 5.

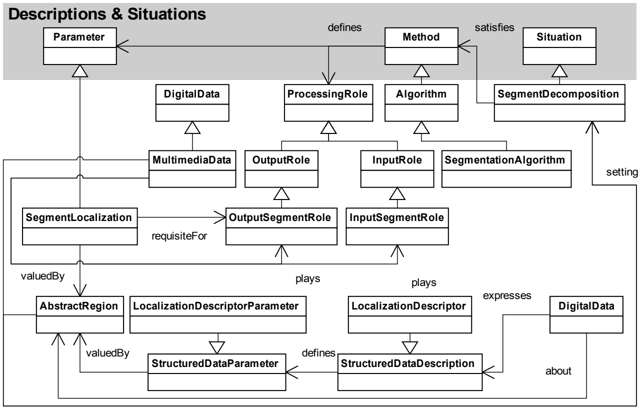

Figure 5: Decomposition Pattern

The formalization of an Algorithm according to the D&S pattern will be introduced in section 4.3.2. In the case of content decomposition, a reasonable application of Parameters could be the inclusion of thresholds which are used to control the process of segmentation, e.g. the minimum degree of homogeneity that is required to merge two areas into one segment.

Of particular importance are the Roles that are defined by a SegmentationAlgorithm or a Method. OutputSegmentRoles are used to indicate that some MultimediaData entities are segments of one MultimediaData entity which plays the role of an input segment (InputSegmentRole). These data entities have as setting a SegmentDecomposition situation that satisfies the rules of the applied SegmentationAlgorithm or Method. OutputSegmentRoles as well as SegmentDecompositions are then specialized according to the segment and decomposition hierarchies of MPEG-7 (see [11], part 5, section 11).

The decomposition pattern, as introduced, is unable to describe the boundaries of a segment. We consider the description of the boundaries (or more generally, the mask in the MPEG-7 terminology) of a MultimediaData entity (which plays a OutputSegmentRole) as an independent annotation, expressed using the content annotation pattern (section 4.2.2). This separation of concerns is necessary to ensure a clear design of the ontology, but does not guarantee that every segment has a mask that specifies its boundary. Therefore, we consider that each OutputSegmentRole must have at least one Parameter (a SegmentLocalization) as requisite, which has to be valued by at least one AbstractRegion that specifies the segment's boundary. These Parameters are defined by StructuredDataDescriptions that are used to store the LocalizationDescriptors defined in MPEG-7 (e.g. `RegionLocatorType`[14] for still regions, see Fig. 10).

4.2.2 Content Annotation Pattern

The attachment of metadata to MultimediaData is formalized by the content annotation pattern which is depicted in Fig. 6. Using the D&S pattern, Annotations become Situations that represent the state of affairs of all related DigitalData (metadata and annotated MultimediaData). DigitalData entities represent the attached metadata by playing AnnotationRoles that specify their meaning. These Roles are defined by Methods or Algorithms. The former are used to express manual (or semi-automatic) Annotation while the latter serve as explanation for the attachment of automatically computed features such as a color histogram of a still region. It is mandatory that the MultimediaData entity which is being annotated plays an AnnotatedDataRole.

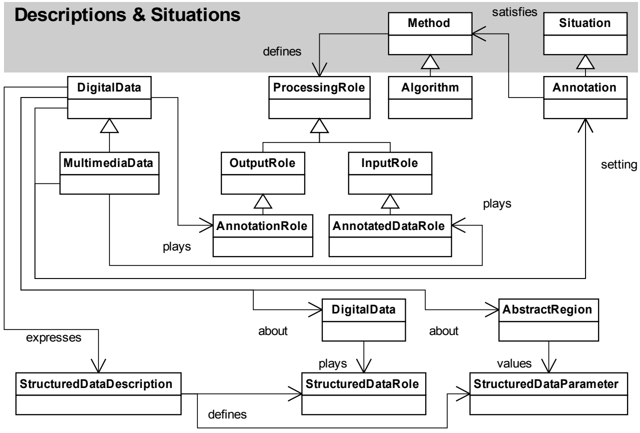

Figure 6: Content Annotation Pattern

AnnotationRoles only provide a rough categorization of the attached metadata. The actual information is represented using the digital data pattern (see section 4.3.1). DigitalData which plays a certain AnnotationRole has to express a StructuredDataDescription that corresponds to the intended meaning of the AnnotationRole. These StructuredDataDescriptions are adopted from MPEG-7. In order to achieve a clean design of the ontology, we apply a strict naming convention between identifiers for instances of StructuredDataDescriptions and names of the related AnnotationRoles. For example, DigitalData, which plays a DominantColorRole within a DominantColorAnnotation, has to express the dominantColorDescriptor which is an instance of the concept StructuredDataDescription (see section 4.3.1). This Description corresponds to the MPEG-7 `DominantColorType`.

4.2.3 Media Annotation Pattern

The media annotation pattern, Fig. 7, forms the basis for describing the physical instances of multimedia content. It differs from the content annotation pattern in only one respect: it is the Media that is being annotated and therefore plays an AnnotatedMediaRole. The multimedia content, i.e. MultimediaData, is annotated indirectly as it is realized by the Media.

One can thus represent that the content of Fig. 1 is realized by a PNG Image with a size of 452 KB, using the MPEG-7 `MediaFormatType`. Using the media annotation pattern, the metadata is attached by connecting a DigitalData entity with the Image. The DigitalData plays an AnnotationRole while the Image plays an AnnotatedMediaRole. An ontological representation of the `MediaFormatType`, namely the StructuredDataDescription instance mediaFormatDescriptor, is expressed by the DigitalData entity. The tuple formed with the scalar "462848"[15] and the string "PNG" is the

[14] Type writer font indicates MPEG-7 language descriptors.

[15] MPEG-7 specifies that the size of a file has to be indicated in bytes. $452 \times 1024 = 462848$.

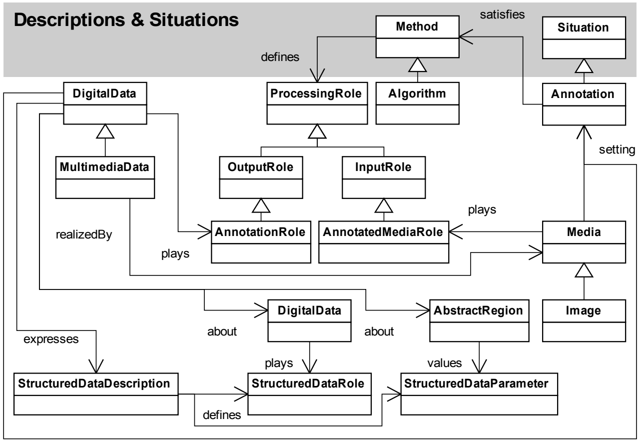

Figure 7: Media Annotation Pattern

value of the StructuredDataParameter instances fileSize and fileFormat respectively. Both instances are defined by the mediaFormatDescriptor.

4.2.4 Semantic Annotation Pattern

The interface between our proposed multimedia ontology and a domain-specific ontology is defined through the semantic annotation pattern, depicted in Fig. 8. Again, this pattern shows many similarities with the content annotation pattern (see section 4.2.2).

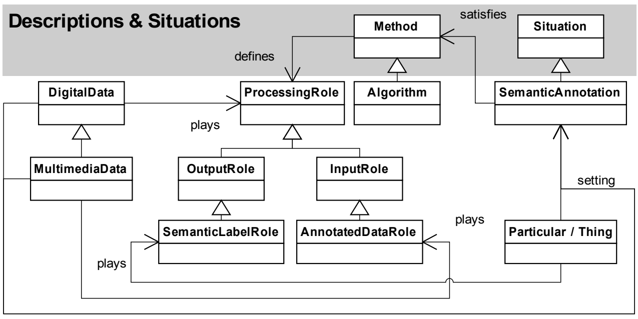

Figure 8: Semantic Annotation Pattern

An OWL Thing or a DOLCE Particular that is depicted by some multimedia content is not directly connected to it. Actually, a manual annotation Method or an Algorithm such as a classification Algorithm, has to be applied to determine this connection. It is embodied through a SemanticAnnotation that satisfies the applied Method. This Description defines that the annotated MultimediaData has to play an AnnotatedDataRole and the depicted Thing / Particular has to play a SemanticLabelRole. The pattern also allows the integration of features which might be evaluated in the context of a classification Algorithm. In that case, DigitalData entities that represent these features would play an InputRole.

We argue that the functionality provided by the semantic annotation pattern is sufficient, and do not formalize the semantic descriptors provided by MPEG-7 (see [11], part 5, section 12) within the multimedia ontology. These descriptors are general concepts for representing domain knowledge but lack formal semantics. An ontology-based multimedia annotation framework should rely on domain-specific ontologies for the representation of the real world entities that might be depicted using MultimediaData. The generic mechanism provided by this pattern allows Martin to use the formal definition of the concept Pipe he found on the web for its semantic annotation. Further knowledge, e.g. about depicted situations in multimedia content, can then be derived using the semantics of the domain ontology and the knowledge about the depicted entities.

4.3 Basic Patterns

Reusing the D&S and OIO patterns for defining the multimedia design patterns is enabled through the definition of basic design patterns which formalize the notion of digital data and algorithms. We will introduce them in sections 4.3.1 and 4.3.2 respectively.

4.3.1 Digital Data Pattern

Within the domain of multimedia annotation, the notion of digital data is central — both the multimedia content being annotated and the annotations themselves are expressed as digital data. We first introduce the pattern which formalizes the concept DigitalData and then discuss its subconcepts, including MultimediaData.

We consider DigitalData entities of arbitrary size to be InformationObjects, which are used for communication between machines. The OIO design pattern states that Descriptions are expressed by InformationObjects which have to be about facts (represented by Particulars). These facts are settings for Situations that have to satisfy the Descriptions that are expressed by InformationObjects. This chain of constraints allows the modeling of complex data structures that are often used to store digital information.

Our approach is as follows (see Fig. 9): DigitalData entities express Descriptions, namely StructuredDataDescriptions, which define meaningful labels for the information (the facts) contained by DigitalData. Facts are represented by mathematical entities such as scalars, vectors or matrices but also strings or polygons. With respect to DOLCE, these entities are AbstractRegions (a subconcept of Region). Regions are described by Parameters in the context of a Description. StructuredDataDescriptions thus define StructuredDataParameters which are valued by the AbstractRegions (the facts) that are carried by DigitalData entities. Situations which satisfy StructuredDataDescriptions are called StructuredDataInstantiations. They serve as settings for the AbstractRegions (mathematical entities) that DigitalData is about.

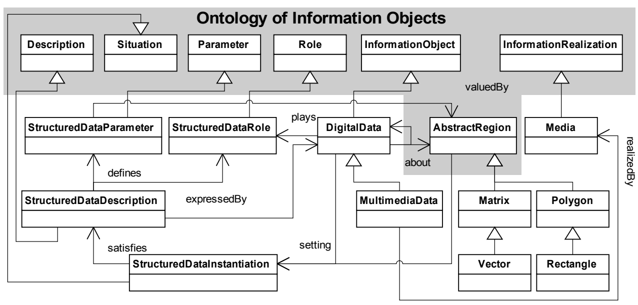

Figure 9: Digital Data Pattern

We use the digital data pattern to formalize most of the complex MPEG-7 low-level descriptors. But instead of defining subconcepts of StructuredDataDescriptions and StructuredDataParameters, we rather create instances of these concepts. We came to this design decision because complex data structures are only needed as labels which identify the type of DigitalData and the information it contains. Fig. 10 shows the application of this modeling approach by formalizing the MPEG-7 `RegionLocatorType` which mainly consists of two elements: a `Box` and a `Polygon`. In the example, the complex type is represented by the instance regionLocatorDescriptor which is the type for (expressedBy) two DigitalData entities. Thus, the `RegionLocatorType` is instantiated twice, e.g. for the description of two image regions. The MPEG-7 `Box` is represented by the StructuredDataParameter instance boundingBox while the MPEG-7 `Polygon` is represented by regionBoundary[16].

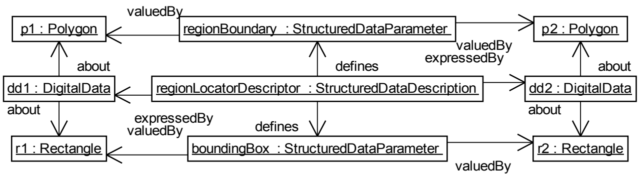

Figure 10: Simplified formalization of the MPEG-7 `RegionLocatorType`.

The MPEG-7 code example given in Fig. 2 highlights that the formalization of data structures, so far, is not sufficient — complex MPEG-7 types can include nested types that again have to be represented by StructuredDataDescriptions. In our example, the MPEG-7 `SemanticType` contains the element `Definition` which is of complex type `TextAnnotationType`. Let us assume that `SemanticType` and `TextAnnotationType` would be represented by the StructuredDataDescription instances semanticDescriptor and textAnnotationDescriptor, respectively. In that case, a DigitalData entity A which expresses the instance semanticDescriptor is about another DigitalData entity B which expresses the instance textAnnotationDescriptor. In order to describe the purpose of B within A, it is required that semanticDescriptor defines a StructuredDataRole, e.g. textAnnotationDefinitionRole, which has to be played by the nested DigitalData B. Analogous to StructuredDataDescriptions and StructuredDataParameters, we use instances of these Roles to formalize nested complex MPEG-7 types.

MultimediaData specializes the DigitalData concept (see e.g. Fig. 9). It is an abstract concept that has to be further specialized by concrete media types such as ImageData that corresponds to the pixel matrix of an image. MultimediaData is realized by some physical Media (e.g. an Image, see Fig. 7). For the multimedia ontology, it is important to include the physical realization of MultimediaData in order to annotate the media itself as we have seen in the section 4.2.3.

4.3.2 Algorithm Pattern

The production of multimedia annotation always involves the execution of Algorithms or the application of computer assisted Methods which are used to produce or manipulate DigitalData. The detection and the classification of an image region is an example of the former, while Martin annotating manually the multimedia content is an example of the latter. We present below the formalization of Algorithms and Methods.

We consider Algorithms to be Methods that are applied to solve a computational problem (see Fig. 11). The associated Situations represent the work that is being done by Algorithms. Such a Situation encompasses DigitalData that is being involved in the computation (Endurants), Regions which represent the values of Parameters of an Algorithm and Perdurants that act as ComputationalTasks (i.e. the processing steps of an Algorithm). An Algorithm defines Roles which

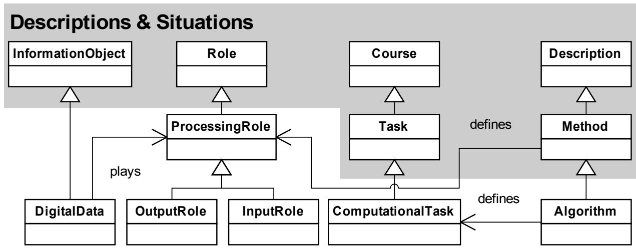

Figure 11: Algorithm Pattern

are played by DigitalData. These Roles encode the meaning of data. In other words, the meaning of DigitalData depends on the Algorithm that has been used to create it. In order to solve a problem, an Algorithm has to process input data and return some output data. Thus, every Algorithm defines at least one InputRole and one OutputRole which both have to be played by DigitalData.

In contrary to StructuredDataDescriptions, it is mandatory that Algorithms, as well as the Roles, Parameters and Courses that they define, have to be formalized as ontological concepts. An instance of a certain Algorithm (e.g. the quick sort algorithm) corresponds to one execution of it. This modeling is required as Algorithms may be applied recursively to data, i.e. the output of an Algorithm could be used again by the same Algorithm as input. An example of this is the recursive segmentation of a segment.

4.4 Comparison with Requirements

We have stated a number of requirements for a multimedia ontology framework in section 3.2. We discuss now whether these requirements are satisfied with our proposed modeling of the multimedia ontology.

The ontology is **MPEG-7 compliant** since the patterns have been designed with the aim of translating the standard into DOLCE. It covers the most important part of MPEG-7 that is commonly used for describing the structure and the content of multimedia documents. Nevertheless, we have not yet considered some parts during the design, that describe the navigation & access to the multimedia content and the user interactions. Our current investigation shows that they can be formalized analogously to the other descriptors through the definition of further patterns. MPEG-7 contains also a number of classification schemes and allows to define its own terminology [23]. We are currently investigating whether the Simple Knowledge Organisation System

[16]The element names in MPEG-7 are not unique across the whole standard as they are locally defined inside each complex type. Therefore, the formalization of them requires the renaming of reappearing element names, e.g. `Polygon`, in order to make them unique across the multimedia ontology.

(SKOS) [21] can be used to represent them. The technical realization of the basic MPEG-7 data types (e.g. matrices and vectors) is not in the scope of the multimedia ontology. For the design, it is not only sufficient but also required to represent them as ontological concepts as the about relationship which connects DigitalData with mathematical entities (e.g. Matrix and Vector) is only defined between concepts. Thus, the definition of data type properties is required to connect instances of mathematical concepts with the actual numeric information. For its serialization, we can use the extended data types for OWL [18, 20].

Syntactic and semantic interoperability of our multimedia ontology is achieved by an OWL DL formalization [17]. Similarly to DOLCE, we will provide also a very rich axiomatization of each pattern using first order logic. The ontology is also opened to the web and can be easily linked to any domain-specific ontology through the semantic annotation pattern (see section 4.2.4).

A clear **separation of concerns** has been taken into account during the design of our ontology thanks to the four different multimedia patterns. Thus, the decomposition pattern (section 4.2.1) handles the structure of a multimedia document, while the media annotation pattern (section 4.2.3), the content annotation pattern (section 4.2.2), and the semantic annotation pattern (section 4.2.4) are useful for annotating respectively the media, the features and the semantic content of the multimedia document.

The various multimedia patterns form the core of the **modular** architecture of the multimedia ontology. We follow the various MPEG-7 parts and organize the multimedia ontology into modules which cover *i)* the descriptors related to a specific media type (e.g. visual, audio or text) and *ii)* the ones that are generic to a particular media (e.g. media descriptors). We have also decided to design a separate module for mathematical entities in order to abstract from the technical realization of non standard datatypes like matrices or polygons.

Due to the multimedia design patterns, our ontology is also **extensible**. It offers the possibility to include further media types as well as more descriptors (e.g. new low-level features) using the same patterns. The underlying D&S pattern allows extensions, by defining additional roles or parameters, of structured data descriptions as well as annotations or decompositions without changing the multimedia design patterns. Therefore, extensions of the ontology will not affect legacy annotations.

5. USING THIS MPEG-7 ONTOLOGY

Martin would like now to adopt our proposed multimedia ontology for annotating the painting depicted in Fig. 1. He does not have to directly manipulate or even understand the various patterns described in section 4. On the contrary, he could use an image annotation tool, such as an extended version of the M-OntoMat-Annotizer[17] that generates annotations according to our proposed multimedia ontology.

The decomposition of the content of Magritte's Image (physically represented by the instance img0) into three still regions is represented by the large middle part of the UML diagram[18] (Fig. 12, A). The still regions are represented by the ImageData instances id1, id2 and id3. The former plays a StillRegionRole while the latter two play an ImageTextRole. The boundaries of the regions are described by a Polygon and two Rectangles respectively which are values for the SegmentLocalizations that are requisites for the SegmentRoles.

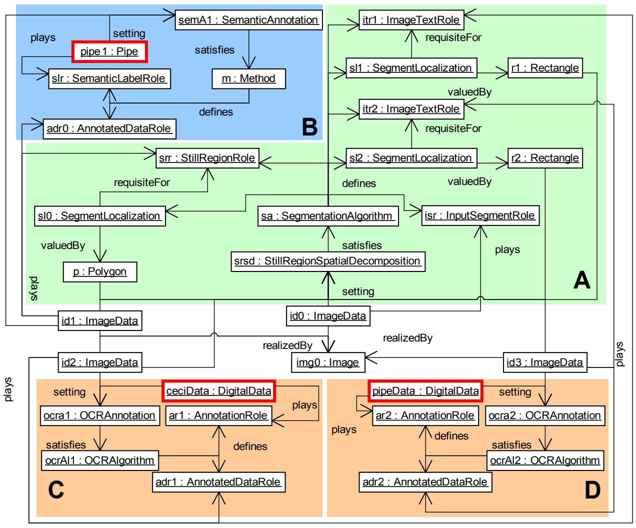

Figure 12: Example Annotation

Using the ontology, a clear distinction between the annotations which are provided by the image annotation tool and the extraction results of the OCRAlgorithms is possible. The former is described by instantiating the semantic annotation pattern (Fig. 12, B). The pipe still region (id1) can be annotated with the instance (pipe1) of the concept Pipe of a possibly existing domain ontology. The strings which have been extracted by running the OCRAlgorithms are attached to the two image text segments id2 and id3 by instantiating the content annotation pattern (Fig. 12, C and D). In order to keep the diagram simple, the extracted strings are not displayed but only the two DigitalData instances ceciData and pipeData are. These two DigitalData instances are about the two extracted strings "Ceci" and "pipe" respectively.

6. CONCLUSION AND FUTURE WORK

In this paper, we have presented an MPEG-7 based multimedia ontology, composed of multimedia patterns specializing the DOLCE design patterns for Descriptions & Situations and Information Objects. We have shown how our well-founded ontology satisfies the requirements, as they are described by the multimedia community itself, for a multimedia ontology framework. The ontology is represented in OWL DL and available on the web at:
`http://multimedia.semanticweb.org/ontology/`.

The ontology already covers a very large part of the standard, and we are confident that the remaining parts will be covered by following our methodology for extracting more design patterns. Our modeling approach confirms that the ontology offers even more possibilities for multimedia annotation than MPEG-7 since it is truly interoperable with

[17] `http://www.acemedia.org/aceMedia/results/software/m-ontomat-annotizer.html`

[18] The scheme used in both Fig. 10 and Fig. 12 is instance:concept as the usual UML notation.

existing web ontologies. The explicit representation of algorithms in the multimedia patterns allows also to describe the multimedia analysis steps, something that is not possible in MPEG-7. The need for providing this kind of annotation is one of the purpose of the AIM@SHAPE project [1], and is detailed in one of the use cases of the W3C Multimedia Semantics Incubator Group[19]. To the best of our knowledge, this is the first attempt to integrate this aspect of annotation in a multimedia ontology.

Our future work will focus on the evaluation of the ontology and its adequacy in the implementation of tools that use it for multimedia annotation, analysis and reasoning.

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7. REFERENCES

[1] H. Eleftherohorinou, V. Zervaki, A. Gounaris, V. Papastathis, Y. Kompatsiaris, and P. Hobson. Towards a Common Multimedia Ontology Framework. aceMedia Project, 2006.

[2] A. Gangemi, S. Borgo, C. Catenacci, and J. Lehmann. Task Taxonomies for Knowledge Content. Technical report, Metokis Deliverable 7, 2004.

[3] A. Gangemi and P. Mika. Understanding the Semantic Web through Descriptions and Situations. In *2nd International Conference on Ontologies, Databases and Applications of SEmantics (ODBASE'03)*, pages 689–706, Catania, Italy, 2003.

[4] R. Garcia and O. Celma. Semantic Integration and Retrieval of Multimedia Metadata. In *5th International Workshop on Knowledge Markup and Semantic Annotation (SemAnnot'05)*, Galway, Ireland, 2005.

[5] J. Geurts, J. v. Ossenbruggen, and L. Hardman. Requirements for practical multimedia annotation. In *Workshop on Multimedia and the Semantic Web*, pages 4–11, Heraklion, Crete, 2005.

[6] J. Hunter. Adding Multimedia to the Semantic Web - Building an MPEG-7 Ontology. In *1st International Semantic Web Working Symposium (SWWS'01)*, pages 261–281, California, USA, 2001.

[7] J. Hunter. Enhancing the semantic interoperability of multimedia through a core ontology. *IEEE Transactions on Circuits and Systems for Video Technology*, 13(1):49–58, 2003.

[8] J. Hunter and L. Armstrong. A Comparison of Schemas for Video Metadata Representation. In *8th International World Wide Web Conference (WWW'99)*, pages 1431–1451, Toronto, Canada, 1999.

[9] A. Isaac and R. Troncy. Designing and Using an Audio-Visual Description Core Ontology. In *Workshop on Core Ontologies in Ontology Engineering*, Northamptonshire, UK, 2004.

[19] `http://www.w3.org/2005/Incubator/mmsem/`

[10] C. Masolo, S. Borgo, A. Gangemi, N. Guarino, A. Oltramari, and L. Schneider. The WonderWeb Library of Foundational Ontologies (WFOL). Technical report, WonderWeb Deliverable 17, 2002.

[11] MPEG-7. Multimedia Content Description Interface. Standard No. ISO/IEC n15938, 2001.

[12] F. Nack and A. T. Lindsay. Everything you wanted to know about MPEG-7 (Part I). *IEEE Multimedia*, 6(3):65–77, 1999.

[13] F. Nack and A. T. Lindsay. Everything you wanted to know about MPEG-7 (Part II). *IEEE Multimedia*, 6(4):64–73, 1999.

[14] F. Nack, J. v. Ossenbruggen, and L. Hardman. That Obscure Object of Desire: Multimedia Metadata on the Web (Part II). *IEEE Multimedia*, 12(1):54–63, 2005.

[15] D. Oberle, S. Lamparter, S. Grimm, D. Vrandecic, S. Staab, and A. Gangemi. Towards Ontologies for Formalizing Modularization and Communication in Large Software Systems. *Journal of Applied Ontology*, 1(2):163–202, 2006.

[16] J. v. Ossenbruggen, F. Nack, and L. Hardman. That Obscure Object of Desire: Multimedia Metadata on the Web (Part I). *IEEE Multimedia*, 11(4):38–48, 2004.

[17] OWL. Web Ontology Language Reference. W3C Recommendation, 10 February 2004. `http://www.w3.org/TR/owl-ref/`.

[18] J. Z. Pan and I. Horrocks. OWL-Eu: Adding Customised Datatypes into OWL. *Journal of Web Semantics*, 4(1):29–39, 2006.

[19] S. Pfeiffer, C. Parker, and A. Pang. Specifying time intervals in URI queries and fragments of time-based Web resources. Network Working Group, Internet-Draft, 2005. `http://www.annodex.net/TR/URI_fragments.html`.

[20] Semantic Web Best Practices and Deployment Working Group. XML Schema Datatypes in RDF and OWL. W3C Working Group Note, 2006. `http://www.w3.org/TR/swbp-xsch-datatypes/`.

[21] SKOS. SKOS Core Guide. W3C Working Draft, 2005. `http://www.w3.org/TR/swbp-skos-core-guide/`.

[22] A. W. Smeulders, M. Worring, S. Santini, A. Gupta, and R. Jain. Content-Based Image Retrieval at the End of the Early Years. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 22(12):1349–1380, 2000.

[23] R. Troncy. Integrating Structure and Semantics into Audio-visual Documents. In *2nd International Semantic Web Conference (ISWC'03)*, pages 566–581, Sanibel Island, Florida, USA, 2003.

[24] R. Troncy, W. Bailer, M. Hausenblas, P. Hofmair, and R. Schlatte. Enabling Multimedia Metadata Interoperability by Defining Formal Semantics of MPEG-7 Profiles. In *1st International Conference on Semantics And digital Media Technology (SAMT'06)*, Athens, Greece, 2006.

[25] R. Troncy and J. Carrive. A Reduced Yet Extensible Audio-Visual Description Language: How to Escape From the MPEG-7 Bottleneck. In *4th ACM Symposium on Document Engineering (DocEng'04)*, Milwaukee, Wisconsin, USA, 2004.

[26] C. Tsinaraki, P. Polydoros, N. Moumoutzis, and S. Christodoulakis. Integration of OWL ontologies in MPEG-7 and TV-Anytime compliant Semantic Indexing. In *16^{th} International Conference on Advanced Information Systemes Engineering (CAiSE'04)*, Riga, Latvia, 2004.

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