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Nr. 4/2007

**Arbeitsberichte aus dem
Fachbereich Informatik**

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Arbeitsberichte des Fachbereichs Informatik

ISSN: 1864-0346

Herausgeber / Edited by:

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

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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 Flickr¹ or YouTube²). All multimedia clientele, producers and consumers alike, however,

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¹<http://www.flickr.com/>

²<http://www.youtube.com/>

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-

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 art³, 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].

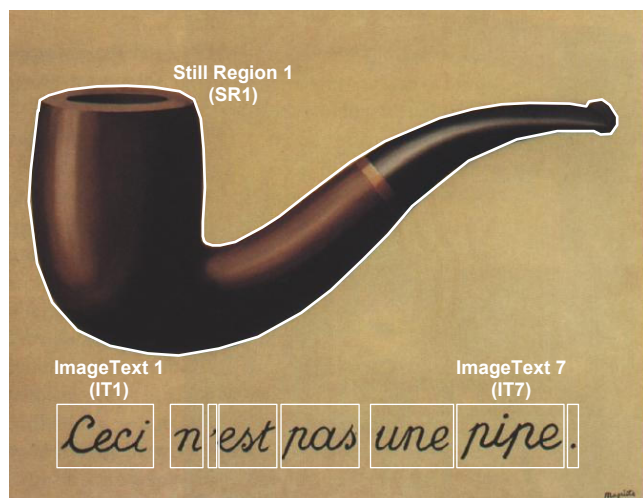


Figure 1: René Magritte, *The Treachery Of Images*. Image adapted from Wikipedia

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

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

identifier has not been 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 tools⁴ 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 coexist⁵. 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 Art⁶ (LACMA) in Los Angeles, California. This (possibly RDF) metadata⁷ 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-

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

⁵See 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 Anytime⁸) 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 Ontology⁹ (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-

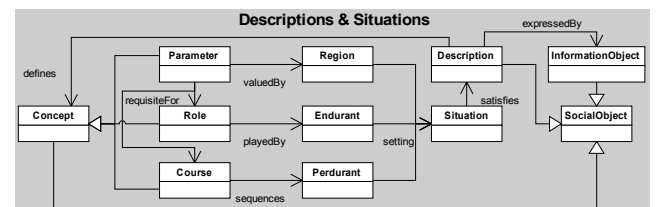


Figure 3: Descriptions & Situations Pattern

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 rela-

tionship between Situations¹⁰ and their Descriptions. Using the D&S extension implies that the basic DOLCE concepts, i.e. Region¹¹, Endurant¹² and Perdurant¹³, 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

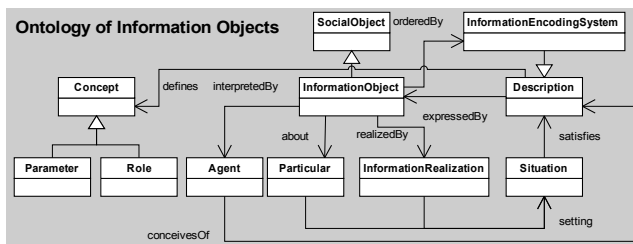


Figure 4: Information Objects Pattern

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

¹⁰Sans serif font indicates ontological concepts.

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

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

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

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

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

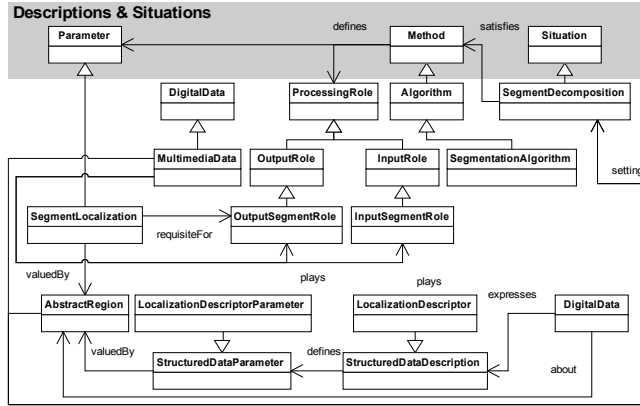


Figure 5: Decomposition Pattern

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*). *Digi-*

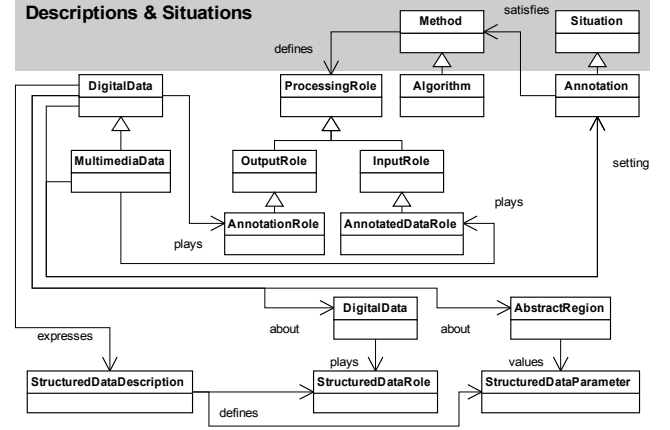


Figure 6: Content Annotation Pattern

talData 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*.

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

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

¹⁴Type writer font indicates MPEG-7 language descriptors.

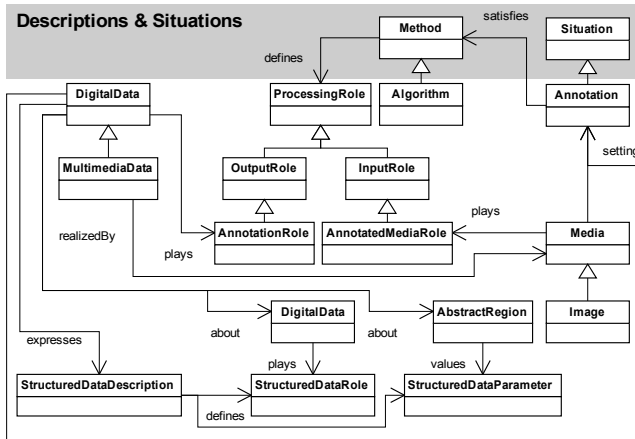


Figure 7: Media Annotation Pattern

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).

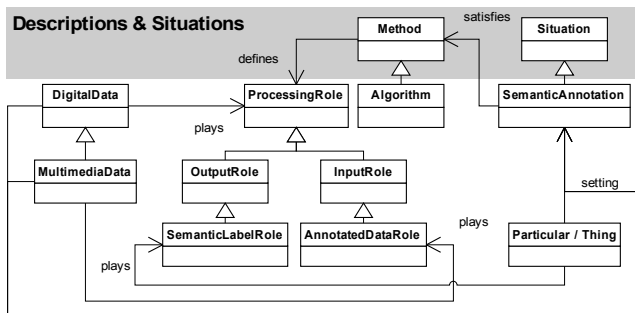


Figure 8: Semantic Annotation Pattern

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 multi-

media 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.

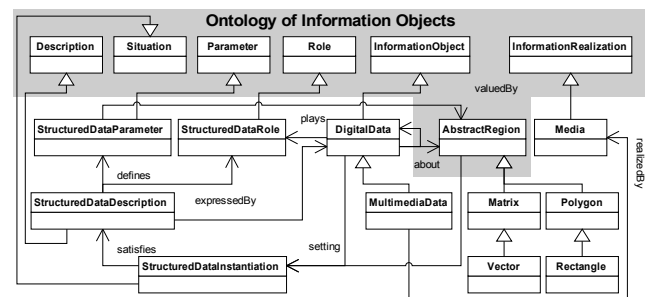


Figure 9: Digital Data Pattern

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.

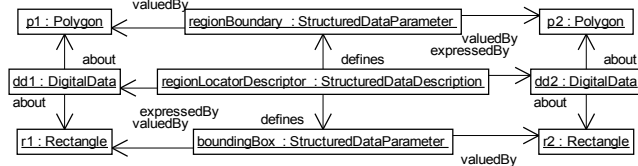


Figure 10: Simplified formalization of the MPEG-7 `RegionLocatorType`.

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

¹⁶The 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.

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

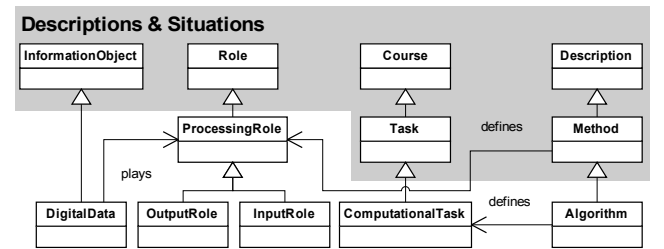


Figure 11: Algorithm Pattern

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

(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-Annotizer¹⁷ 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

diagram¹⁸ (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**.

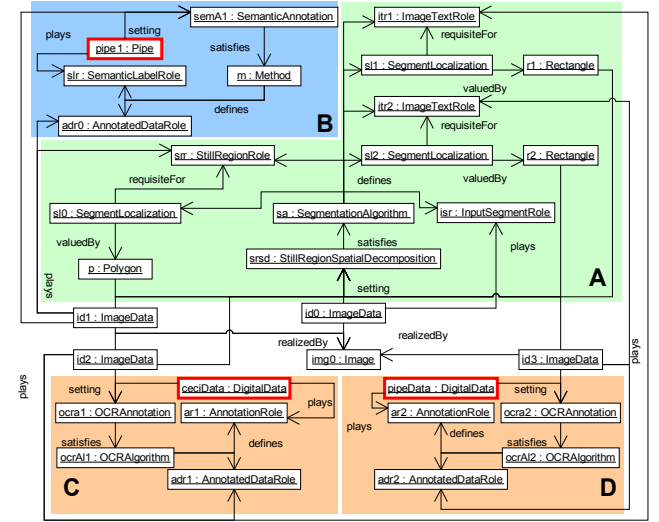


Figure 12: Example Annotation

Using the ontology, a clear distinction between the annotations which are provided by the image annotation tool and the extraction results of the OCRAAlgorithms 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 OCRAAlgorithms 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>

¹⁸The 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 Group¹⁹. 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.

Acknowledgements. The authors would like to thank Antoine Isaac, Frank Nack, Jacco van Ossenbruggen and Miroslav Vacura for their feedback. The research leading to this paper was partially supported by the European Commission under contract FP6-027026, Knowledge Space of semantic inference for automatic annotation and retrieval of multimedia content – K-Space, under contract FP6-026978, X-Media Integrated Project, and the European ITEA Passepartout Project.

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¹⁹<http://www.w3.org/2005/Incubator/mmsem/>

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