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An Ontology-Based Approach of Multimedia Information Personalized Search

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Abstract. This paper discusses and provides a solution for the problem of adopting ontologies in order to model the users and the multimedia documents and to develop personalized search functionalities. First, the existing approaches that enable ontology-based semantic description of multimedia content are discussed. Then, current ontology-based solutions for personalized search functionalities inside adaptive hypermedia systems are presented. Our solution is exposed further, including the multimedia document model, the user profile development and the algorithmic solution that enables to provide personalized results to a user query.

Keywords: multimedia management, semantic annotations, ontologies, information indexing, personalized search.

1 Introduction

In the context of the multimedia information systems with an increasing number of available resources, the searching activity should be tailored to each user needs and interests. In order to be effective, the results provided to a user query should be provided according to the current user profile, which could include his/her preferences, tastes, backgrounds, knowledge or interests. In order to develop such personalized search facility, a matching between user queries, user profile and document representations should be accomplished.

This paper discusses and provides a solution for the problem of adopting ontologies in order to model the users and the multimedia documents and to develop personalized search functionalities. The main idea is to analyze the user queries according the ontology concepts and to execute them against the ontology-based documents metadata. In the beginning, the paper discusses the existing approaches that enable ontology-based semantic description of multimedia content are. Then, current ontology-based solutions for personalized search functionalities inside adaptive hypermedia systems are presented. Our solution is exposed further, including the multimedia document model, the user profile development and the algorithmic solution that enables to provide personalized results to a user query.

2 Ontology-Based Multimedia Content Description Approaches

In order to describe administrative, technical or physical features of the multimedia content, a lot of XML-based vocabularies were developed and standardized for different content types:

- *Images*: Exchangeable Image File Format (Exif)¹, IPTC Photo Metadata², VRA Core³, NISO Z39.87⁴, DIG 35⁵, PhotoRDF⁶.
- *Audio-visual content*: MPEG-7 (Multimedia Content Description Interface)⁷, MXF (Material Exchange Format)⁸, AAF (Advanced Authoring Format)⁹, ID3¹⁰, MusicBrainz¹¹, MusicXML¹², EBU P/Meta, MPEG 21;
- *Text*: TEI (Text Encoding Initiative)¹³.

The problem of semantically describing the content itself through a metadata-based layer of meaning such as to make the multimedia content semantics transparent to computer applications [1] could not be solved exclusively with the support of these vocabularies. Ontologies constitute the main instrument for developing such transparent semantic annotations of the multimedia content.

Ontologies are used mainly for two purposes with respect to the multimedia content:

- to provide semantic expression for the multimedia structural metadata expressed in XML vocabularies. As an integrant framework, the ontology provides in this case as well support for the interoperability issues between these vocabularies.
- to provide a semantic description of the multimedia content independently from the XML-based specialized vocabularies, e.g. based on domain ontologies.

While our solution is developed from the second purpose perspective, we present further some existing approaches following the both purposes: the domain ontology-based semantic descriptions have to be added up to the multimedia structural semantic metadata.

¹ Exif Version 2.2, Japan Electronics and Information Technology Industries Association: http://www.digicamsoft.com/exif22/exif22/html/exif22_1.htm

² <http://www.iptc.org/IPTC4XMP/>

³ <http://www.vraweb.org/projects/vracore4/>

⁴ <http://www.niso.org/>

⁵ <http://xml.coverpages.org/FU-Berlin-DIG35-v10-Sept00.pdf>

⁶ <http://www.w3.org/TR/2002/NOTE-photo-rdf-20020419>

⁷ <http://www.chiariglione.org/mpeg/standards/mpeg-7/mpeg-7.htm>

⁸ <http://www.smpte-mxf.org/>

⁹ <http://www.aafassociation.org/html/techinfo/>

¹⁰ http://www.id3.org/Developer_Information

¹¹ <http://musicbrainz.org/MM/>

¹² <http://www.recordare.com/xml.html>

¹³ <http://www.tei-c.org/>

2.1 Ontologies That Integrate XML-Based Vocabularies

Some ontologies were developed that aim to provide integrative support for describing all the multimedia features no matter of their initially XML-based expression. Such solutions include *COMM* ontology (<http://comm.semanticweb.org/>), *ABC* [2] or *aceMedia* ontology (<http://www.acemedia.org/>), all of them being developed on the top of MPEG7 vocabulary. The differences between them concern the coverage of the entire MPEG7 specification, as well as the maintenance of the initial MPEG7 structure.

The *aceMedia Ontology Framework* [3] define an integrated multimedia annotation framework based on a core ontology (DOLCE), two multimedia MPEG-7 based ontologies (VDO - Visual Descriptor Ontology - and MSO - Multimedia Structure Ontology), as well as domain ontologies such as PCS (Personal Content Management) and CCM (Commercial Content Management) Ontologies.

DELOS II Network of Excellence [4] defined an MPEG-7 upper ontology, which was extended with Semantic User Preference Description ontology and harmonized with MPEG 21 DIA Ontology, as well as with *SUMO* and *DOLCE* core ontologies in order to acquire an integrated annotation framework. *GraphOnto* was adopted as visual ontology-based annotation tool for multimedia content.

The goal of *COMM (Common Ontology for Multimedia)* ontology is to describe the semantics of multimedia content in terms of current semantic Web languages [5]. The *COMM* ontology exploits and extends the structure of the MPEG-7 specifications in order to provide support for organizing the multimedia metadata; *COMM* ontology provides also support for expressing all the multimedia features covered by the MPEG-7 specification, which forms a really huge set. The advantage of its formal semantics consists in enabling these features' expression, independently of the XML-based vocabulary through which the features were initially expressed. In other words, *COMM* provides support to express all the XML-based multimedia metadata having synonyms in MPEG-7 specification.

2.2 Ontology-Based Multimedia Content Semantic Description Approaches

Some specialized multimedia ontologies were also developed in order to capture and express the high-level semantics for multimedia objects: *aceMedia Visual Descriptor Ontology*, *mindswap Image Region Ontology*, *MSO - Multimedia Structure Ontology*, *VDO - Visual Descriptor Ontology*, *AIM@SHAPE* ontology for representing, modeling and processing knowledge which derives from digital shapes, *Music Information ontology*, *Semantic User Preference Ontology* developed to be used in conjunction the MPEG-7 MDS Ontology and with domain ontologies, in order to interoperate with MPEG-7 and allow domain knowledge utilization, *CIDOC CRM* core ontology for all multimedia objects, especially concerning cultural heritage items and events.

As could be noticed, there is a lot of support for expressing and organizing the multimedia semantic metadata, but not a generally accepted integrated framework. In order to manually develop such semantic metadata, different frameworks and tools were developed. Because of the high cost involved by this operation, multiple approaches to automatically obtain such semantic metadata were also developed, mainly around some concrete multimedia systems. We present below some representative approaches, where obtaining semantic metadata constitute an important step in integrating multimedia content in various personalized or customized functionalities. We present further some important existing examples.

In [1], a video content annotation architecture built on PhotoStuff image annotation tool¹⁴ is used to link MPEG-7 visual descriptors (obtained through automatic multimedia processing) to high-level, domain-specific concepts. The manually obtained multimedia semantic metadata is further used in order to improve the browsing and searching capabilities.

In [6] is presented a system where the multimedia content is annotated through three ontologies: the developed ontology on the top of MPEG-7, and two domain-specific ontologies. In order to enable the semantic interoperability, the three ontologies are merged with the support of ABC top-level ontology [2]. Alongside with the manual annotation, domain-specific inferencing rules are defined by domain-experts through an intuitive user-friendly interface in order to automatically produce supplementary semantic metadata.

In METIS project [7], the multimedia content is organized into a database, characterized by customizable media types, metadata attributes, and associations, which constitutes a highly expressive and flexible model for media description and classification. The multimedia ontology-based annotations could be also defined, due to the developed plug-in for the open-source Protégé ontology editor. The authors provide as case study the implementation of an archive system for research papers and talks in the Computer Science domain, classified according the ACM classification system. The semantic annotations are developed by the users, via a Web annotation interface. Scientific resources are thus available for browsing, classification, and annotation through the standard METIS Web administration interface.

The project aceMedia adopts manual ontology-based multimedia annotations, with the support of M-OntoMat-Annotizer. As well, the project developed a multimedia analysis system for automatically annotate the multimedia content based on the developed aceMedia Visual Descriptor Ontology. The system includes methods that automatically segment images, video sequences and key frames into a set of atom-regions while visual descriptors and spatial relations are extracted for each region [3]. A distance measure between these descriptors and the ones of the prototype instances included in the domain ontology is estimated using a neural network approach for distance weighting. Finally, a genetic algorithm decides the labeling of the atom regions with a set of hypotheses, where each hypothesis represents a concept from the above mentioned

¹⁴ <http://www.mindswap.org/2003/PhotoStuff/>

domain ontology. This approach is generic and applicable to any domain as long as specific domain ontologies are designed and made available.

As could be noticed, there are multiple ontology-based modeling solutions that enable to adopt an ontology-based description of the multimedia content. Mainly, some of them enable to express the common multimedia document features, such those mentioned in Section 2.1. In addition, some more detailed semantic descriptions of the multimedia content, expressed through domain ontology, are obtained manually or into a semi-automatic manner that exploits some inference rules or classification algorithms.

We will present further some representative approaches where the multimedia semantic annotations are considered for multimedia retrieval functionalities. Moreover, some approaches are outlined that consider user characteristics when responding to his queries.

3 Using Ontologies for Developing Multimedia Retrieval and Personalized Search Functionalities

3.1 Ontology-Based Multimedia Retrieval

The existing retrieval mechanisms implement an efficient ranking algorithm applied to the results provided for a certain query. Many ranking methods were introduced, based on clever term-based scoring, link analysis, evaluation of user traces etc. [8].

In [9] the MPEG-7 OWL ontology¹⁵ is used as upper-level multimedia ontology where three different music ontologies have been linked in order to annotate the multimedia content. System architecture is proposed that facilitates multimedia metadata integration and retrieval.

In SAFIRE project [10] MPEG-7 structure is used as basis for organizing multimedia features. Alongside with automatically extracted features, the semantic annotations are accomplished manually, using WordNet ontology in order to acquire disambiguate annotations. These annotations are exploited together with their synonyms for increasing the efficiency of the further query process.

In [11], ontology is used in order to define the video database model. Such ontology must be previously developed for a certain modeled domain, containing definitions of objects, events and concepts in terms of attributes and components. The system applies in a first phase a set of automatic multimedia processing techniques in order to segment the video into regions, and to extract features for each region (color, shape, color distribution etc.). If some regions have similar properties for a period of time (consecutive keyframes), the possible occurrence of an object could be inferred. By using similarity functions, objects identified from regions are assigned to their actual names by using information gained from the training set developed by experts according the considered ontology. The ontology-based data model enables the system to support ontology-based queries,

¹⁵ <http://rhizomik.net/ontologies/mpeg7ontos/>

able to specify objects, events, spatio-temporal clauses, trajectory clauses, as well as low-level features of objects.

In [12], a method is proposed for searching a document collection via queries that are constituted by ontology concepts. The ranking algorithm considers these concepts as distinct key-phrases, while the ontological relations are not exploited.

[13] describe a system with ontology-based annotation and retrieval capabilities for managing the audiovisual information. After the multimedia segmentation process, the annotations are made by specialists, by making reference to some previously selected ontologies, and stored in the semantic base. The search mechanism, implemented as an API, provides support for semantic queries, based on the some provided search templates.

As could be noticed, in the various frameworks are developed that exploit multimedia metadata mainly for a better information retrieval, that do not take into account the particularities of the user that accomplishes the search: for a specific query, the same results are provided to all users. Different approaches that consider user characteristics when responding to a user query were developed in the area of adaptive hypermedia systems, and some of them consider ontology-based content descriptions.

3.2 Ontology-Based Personalized Search

Given a particular user keyword-based query, the personalized search systems provide results that are tailored to the preferences, tastes, backgrounds and knowledge of the user who expressed it [14]. In systems that adopt ontological modeling, retrieving documents for a certain user query means in fact querying documents by the ontology concepts included into the query and filtering them based on the user model.

[15] describe Bibster, a Semantics-Based Bibliographic Peer-to-Peer System, which uses ACM ontology together with SWRC ontology in order to describe properties of the scientific publications. The retrieval mechanism makes also use of a learning ontology, developed on the fly, in order to reflect the actual content of the individual users. ACM ontology was also used, together with SWEBOK ontology in order to refine the e-learning materials annotation [16].

[17] develop an ontology for reformulating and storing the user queries in a semantic enriched form; in order to approximate the meaning of users' queries each query term is mapped to a Word-Net sense. The retrieval mechanism computes the similarity of documents and the already constructed query ontology, by using the AUTOMS5 proposed method that combines lexical, semantic, and structural matching methods.

[18] define a conceptual architecture for a personal semantic Web information retrieval system. The user requirements are reflected by his/her preferences, profile and constraints along with a query. A formal query is composed of three types of element fields: user preferences (UPs), content query (CQ) and Web service query (SQ). The responses combine Web content relevant to the query, but also information about the Web services potentially relevant to the user.

In general, the personalized search systems develop the user profile in terms of the history of user's keyword-based queries, correlating it with the document annotations. Personalization process could consider the user profile into one of three moments: during the retrieval process, in a distinct re-ranking activity or in a pre-processing of the user query [14].

We will expose further our personalized search solution were a same ontology is adopted in order to model the user query, the user profile and the document content.

3.3 Ontology-Based Solution for Personalized Search Inside Multimedia Systems

We present further an ontology-based solution for developing customized responses to the user queries. Domain ontology is adopted for modeling the user query, the user profile and the multimedia documents, as well as for locating pertinent result documents for the user query. The solution capitalizes some previous work while bringing also some new contributions.

Considering the medical domain and the MESH¹⁶ as example ontology, we will adopt a vector representation of its $n=25.588$ main concepts ("preferred terms"), alongside with an OWL ontology representation¹⁷ that enables to store as well the relations between concepts. Let us designate as $C[i]$, $i=1, n$, the vector that stores the MESH concepts. The n dimension will be further adopted for multiple vectors containing weights of MESH ontology concepts (the i th element correspond to the i th@ concept) and describe the document model, user query or user profile, as illustrated in the following sections.

Multimedia Documents Model and Representation. As we mentioned, in order to model the semantic metadata associated with multimedia documents, we need an ontology that provide support for expressing the common multimedia features, and one or more domain ontologies through which the semantic of the multimedia content to be expressed. Harmonizing and integrating the both types of ontologies constitutes a problem itself.

Due to its extensive covering character of MPEG-7 descriptors, we consider the COMM ontology for representing the common multimedia features. As well, considering the particular case of medical domain, we adopt MESH ontology to describe the content itself of the multimedia content. We have to locate the better solution for binding these two ontologies.

COMM ontology uses DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering)¹⁸ as a modeling basis, and it defines some modeling patterns [5]:

- *Decomposition*: exploits MPEG-7 descriptors for spatial, temporal, spatiotemporal and media source decompositions of multimedia content into segments.

¹⁶ <http://www.nlm.nih.gov/mesh/>

¹⁷ <http://bike.snu.ac.kr/sites/default/files/meshonto.owl>

¹⁸ <http://www.loa-cnr.it/DOLCE.html>

- *Annotation*: exploits the MPEG-7 very large collection of descriptors that can be used to annotate a segment. The annotations are associated to a particular media content region (or to the entire media document):
 - *Content Annotation*: for annotating the features of a multimedia document, which means for expressing its associated metadata (media-specific metadata/ For example, DominantColorAnnotation expresses the connection between a MPEG-7 DominantColorType with a segment.
 - *Media Annotation Pattern* - for describing the physical instances of multimedia content (general metadata). For example, MediaFormatType enable to express features such as FileSize=“462848”, FileFormat=“JPEG”;
 - *Semantic Annotation Pattern* (semantic metadata) - allow the connection of multimedia descriptions with domain descriptions provided by independent domain-specific ontologies.
- *Digital Data pattern* is used to formalize most of the complex MPEG-7 low-level descriptors.
- *Algorithm pattern* defines:
 - Methods - for the manual (or semiautomatic) annotations;
 - Algorithms - for automatically computed features (e.g. dominant colors) Every Algorithm defines at least one InputRole and one OutputRole which both have to be played by DigitalData.

As could be noticed, the Semantic Annotation Pattern acts as an interface between COMM and a domain-specific ontology (see Figure 1). It enables to include inside the COMM-based multimedia metadata some semantic metadata expressed through domain ontology concepts. We adopt this facility in order to integrate in the multimedia annotation the MESH concepts that describe the content of the current multimedia document. For representing these concepts, we adopt the technique exposed in the beginning of this chapter. For a specific multimedia document D_j , the MESH-based annotation are represented through a vector $D[j,i]$, $i=1,n$ ($n=25.588$), where each element $D[i,j]$ represents the weight of the concept $C[i]$ in the representation of the document D_j .

In [19] we presented a method for automatically obtaining this simplified representation in the case of textual documents. After a pre-processing phase, the terms frequency matrix associated to the document D_j suffers a dimension reduction through the latent semantic analysis technique: from a t -dimension corresponding to the detected t keywords, it is reduced to a k -dimension, where $k \ll t$. For each ontology concept, a t -dimensional vector representation is initially considered, which is reduced further to the same k -dimension. The distance between the dimensionally reduced concept vectors and the document vectors lead to detecting each concept weight for a document.

Images and audio-visual documents constitute a special challenge for indexing approaches because of their binary character [20]. However, some steps are done, and in we [21] exposed some preliminary results.

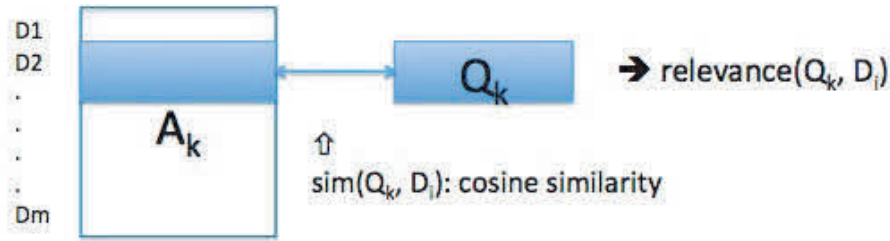
In order to facilitate the comparison between a user query and the available document models, we should represent the user query in a similar manner, namely a vector of concept weights. Thus, for a query Q , $Q[i]$ will mean the weight of the concept $C[i]$ in the query Q , where $i=1,25.588$. As example, a query like “pancytopenia in aids, workup and etiology” will be characterized by the MESH preferred terms “Pancytopenia - C15.378.700”, “AIDS-Related Complex - C20.673.480.080”, “Work - I03.946”.

However, such a concept-based vector representation is not obviously to be obtained. Remaining coherent with the document processing, we rely our technique on the query keywords. First, the relevant documents for the specified query are obtained:

- The query is represented first as a huge t -dimension vector $Q'[i]$ (where t is the same dimension as in the case of keyword-based document vectors);
- $Q'[i]$ receive value 1 for the positions corresponding to the query words, 0.5 for the positions corresponding to synonyms of the query-words (according Wordnet), and 0 on the others positions.

As example of synonymic variant for the specified we could mention “erythrocytes, leukocytes and platelets deficiency in Acquired Immuno-Deficiency Syndrome and pathogenesis”.

- The resulted $Q'[i]$ vector is reduced to the k dimension through the Singular Value Decomposition technique proper to the latent semantic analysis method.
- The pertinence of a document D_j for a user query Q will be given by the cosine similarity between their reduced k -dimension representations:



$$Q[i] = \frac{\sum_{j=1}^{10} D_j[i]}{10}, i = 1, 25588 \quad (1)$$

The first ten documents are selected having the biggest similarity to the current user query. However, in order to establish their order of pertinence for the current user, the user profile should be considered, as illustrated in the next section. Based on the determined top ten relevant documents for the specified

query, the concept-based query representation is obtained as the average of these documents' representations:

$$Sim(D_j, Q') = cos(D_j, Q') = \frac{D_j Q'}{|D_j| |Q'|} \quad (2)$$

3.5 User Profile Development

The adaptive hypermedia systems adopt a feature-based modeling technique, considering some important characteristics of the user as an individual: knowledge, interests, goals, background, and individual traits [24]. Three solution types were defined for modeling the user profile, based respectively on a keywords set, on a specific semantic network, or on a set of concepts belonging to multiple existing semantic networks, which could be taxonomies, topic maps, or even ontologies [24].

The user goals represent the most dynamic user characteristic since it illustrates his/her current activity, namely the run queries and the accessed documents among those returned as a query result. We adopt a user model that expresses the user current goals. The above presented vector representation for documents and queries enable to develop a similar user profile representation. It consists into a vector $U[i]$, $i=1,n$, where $U[i]$ represents the user interest degree concerning the concept $C[i]$, as deduced upon his provided queries and accessed documents.

- At the beginning of the working session, $U[i]=0$, $i=1,n$;
- When the user provides a query Q for expressing his current goals, the concepts mentioned by the query are included in his profile: $U[i] += Q[i]$, $i=1,n$;
- When the user accesses a document provided as a result to his query, the concepts that characterize the document D_j are also included in his profile: $U[i] += D[j,i]$, $i=1,n$;

It could be noticed that our solution consist in representing user goals as concept weights, while the user queries and accessed documents are not necessary to be stored. Their information is condensed into the $U[i]$ vector representing user profile.

3.6 Providing Customized Results to the User Query

We present further the steps of our algorithmic solution for for responding into a personalized manner to the user queries:

1. At the beginning of the working session, the user profile is empty: $U[i]=0$, $i=1,n$;
2. The user provides a query Q for expressing his current goals; the query is processed as it is described in Section 4.2;
3. The user profile is updated with the concept weights corresponding to the query: $U[i] += Q[i]$, $i=1,n$.

4. The similarity between this query and the representations of the available documents is calculated, and the list of documents with a similarity over a threshold τ is retained;
5. If this list is null, then the query Q is enriched by considering the parents of the component concepts, while reducing their weight with 50 percents (the degree of interest decreasing from a to $a/2$);
6. If this list is not null, then it is re-ordered according the cosine similarity between user profile and each document vector. The list is displayed to the user;
7. When the user accesses a document provided as a result to his query, the concepts that characterize the document D_j are also included in his profile: $U[i] += D[j,i]$, $i=1,n$;
8. When the user provides a new query, the elements of his current profile are divided by 2 in order to decrease the importance of his previous goals while emphasizing the goals expressed through the new query;
9. This query is considered by re-starting the step 2.

The ontology-based vector representations enable a very simple filtering process based on the cosine similarity between vectors, as Figure 2 illustrates.

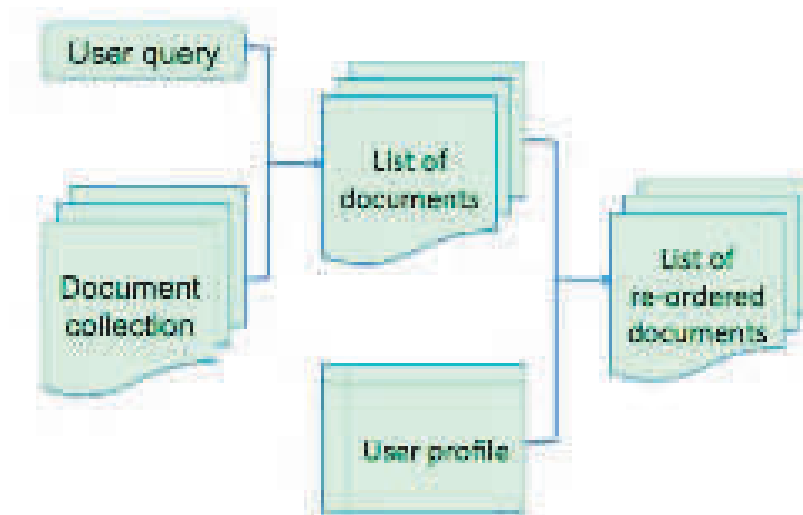


Fig. 2. The gradual filtering process based on ontological representation in the personalized search

3.7 Conclusions and Further Work

In this paper we presented a solution for the problem of adopting ontologies in order to model the user profile, the user queries and the multimedia documents. Despite some structured representations are available, are discussed and

are exploited for these resources, we adopted also a simplified vector representation that facilitates the matching and filtering processes that lead to the final personalized results list.

The present paper proposes a model that enables to semantically describe the multimedia content. This model is presented in the context of existing approaches that adopt ontologies in order to annotate multimedia resources. Its particularity consists in a simple solution for integrating domain ontology-based semantic annotations in the structure of the COMM ontology-based descriptions of the multimedia content, without requiring a special binding. Thus, the domain ontology considered in annotations is kept independently, while inside the COMM structure is included just information about the concepts and their weights for the current multimedia document.

The presented personalized search technique adopts the same domain ontology for representing user queries and for developing user profile.

We already worked in exploiting the semantic annotations associated with different resource types inside an existing tracking system that capture the user current activity, which is developed based on the Contextualized Attention Metadata (CAM)¹⁹ framework. In [26] we exposed a solution for recommending documents to users according to their current activity that is tracked in terms of semantic annotations associated to the accessed resources. We intend to extend this framework in order to handle the user query in the spirit of the presented semantic oriented approach. Tests using various multimedia collections are also considered for our future research explorations.

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¹⁹ http://www.ariadne-eu.org/index.php?option=com_content&task=view&id=39&Itemid=55

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