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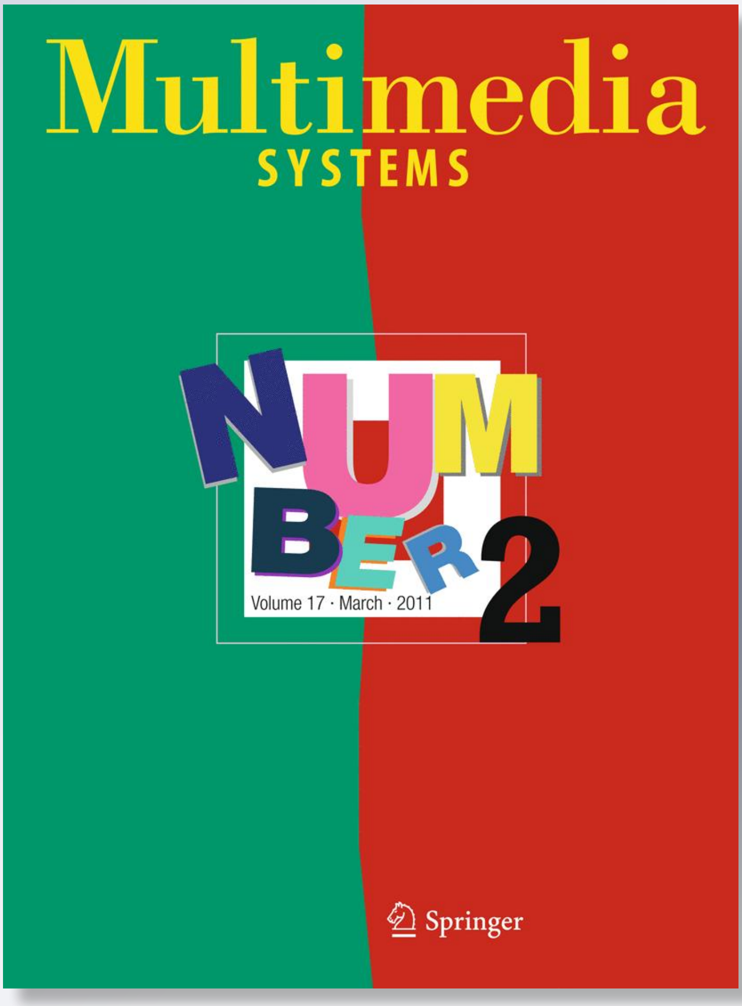

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REGULAR PAPER

A middleware to enhance current multimedia retrieval systems with content-based functionalities

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Abstract Nowadays the retrieval of multimedia assets is mainly performed by text-based retrieval systems with powerful and stable indexing mechanisms. Migration from those systems to content-aware multimedia retrieval systems is a common aim for companies from very diverse sectors. In this paper we present a semantic middleware designed to achieve a seamless integration with existing systems. This middleware outsources the semantic functionalities (e.g. knowledge extraction, semantic query expansion,…) that are not covered by traditional systems, thereby allowing the use of complementary content-based techniques. We include a list of key criteria to successfully deploy this middleware, which provides semantic support to many different steps of the retrieval process. Both the middleware and the design criteria are validated by two real complementary deployments in two very different industrial domains.

keywords Multimedia information retrieval · Content-based · Semantic middleware

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1 Introduction

The explosion of multimedia content caused by the digitalization and the convergence of the technology has led to a new revolution in, among others, two scientific fields, blurring the dividing boundaries between them: information retrieval (IR) and image and video analysis.

On the one hand, in the IR field, the inclusion of multimedia assets implies new means for the storage, retrieval, transportation, and presentation of data with very heterogeneous features such as text, video, images, graphs, audio, and the like. Baeza et al. [3] in their book on the modern concept of Information Retrieval already include several chapters focused on techniques and approaches to retrieving multimedia assets, as an emerging particularity of IR. The motivation behind this new activity is due to the fact that traditional IR techniques are very efficient from the performance and precision point of view when the fundamental unit is the textual document and the search is based on text and carried out over simple data types. However, in the case of multimedia information retrieval the underlying data model, the query language, and the access and storage mechanisms *must be able to support objects with a very complex structure*. Furthermore, the scientific work devoted to establishing the foundations of the next generation of multimedia information retrieval systems, such as the remarkable contribution of Meghini et al. [28], are slowly having an impact on commercial products. An example of this preliminary deployment of such concepts is the last version of the multimedia database of Oracle, which is able to handle and perform certain operations on new object types (e.g. DICOM images from the medical sector).

On the other hand, the image and video community has devoted remarkable efforts over the recent years to promote what they coin as "Content or semantic based visual/

multimedia information retrieval" (CBVIR) [23, 29]. According to Zhang [54], CBVIR has already a history of 15 years, but it is only recently that the focus has shifted from extraction of low-level features from the multimedia assets (e.g. dominant colour in an image) to the resolution/minimization of the semantic gap (e.g. person recognition). The community is devoted to a higher level of semantic abstraction, which the aforementioned author calls Semantic-based Visual Information Retrieval, and which is leading to the application of these technologies for the enhancement of current multimedia management and retrieval systems. Among the processes being improved, we may highlight the following: Indexing and retrieval, higher-level interpretation, video summarization, object classification and annotation, and object recognition. We also want to point out that in all these disciplines, the presence of the technologies developed by the semantic web community has been significantly increasing over the past years [47] . As we will see in Sect. 5, the use of ontologies, fuzzy reasoners, and semantic rule engines are providing very appealing results on many of the disciplines or sub-processes of the semantic-inclusive multimedia management and retrieval.

Nevertheless, when we observe the multimedia retrieval technology that has been transferred to the industry, we find that the companies are mainly employing optimized and powerful retrieval engines based on the traditional IR algorithms [7]. There is an important technology transfer gap for the advances related to the fields of multimedia and content-based information retrieval. The changes introduced in commercial database technology are not powerful enough [12] to enable the integration of the techniques developed by the video community [46].

Based on our own experience, the willing for such an integration is there. However, in many cases the first obstacle to be overcome for the transferring of the technology is the guarantee for the coexistence of the current systems with the emerging techniques. Companies are very used to traditional IR technology, its robustness, and high performance. For instance, we worked with broadcasting engineers eager to enrich their system with new content-based functionalities, but their first overriding was that the core of their media asset management, a professional last generation relational database, should not be replaced, nor in the least affected.

In such a context, the contribution presented in this paper is a focused effort to enhance current information retrieval systems by facilitating the integration of semantic or content-based techniques into those systems. Contrary to Meghini [28], we are not proposing a revolutionary paradigm for multimedia retrieval but a straightforward and simpler approach to enriching current IR systems with successful semantic applications that benefit from the understanding of the multimedia asset.

We propose a three-layered semantic middleware that has been designed to provide semantic services needed by different content-based applications involved in conventional multimedia retrieval workflow. The main feature of this middleware is that it centralizes the semantic knowledge and the provision of semantic services in the system. Below, we summarize the main advantages of our proposal:

- *Outsourcing*. The middleware facilitates the integration into existing systems since the semantic services are outsourced from the retrieval engine(s).
- *Uniqueness*. The middleware avoids current semantic duplicities imposed by the employment of satellite applications (e.g. content-based recommendation, ontology-based clustering). This simplifies the work of knowledge engineers, since the upgrading of the knowledge representation of the domain is performed in a single place.
- *Semantic interoperability*. The middleware includes a semantic representation of the knowledge which is format-agnostic. In those cases where the middleware is working with components or information sources that employ different formats or languages, the architecture of the middleware provides simple mechanisms to perform the needed adaptations and carry out the upgrades derived from the evolution of each of the peers.

Moreover, we demonstrate the feasibility of our middleware in two real scenarios. In the first one [27], the middleware is integrated into a system that searches different multimedia items (documents, images, and graphs) from different information sources of the car industry. The domain covers aspects regarding the design and engineering of cars and engines. The information sources tackled are an ASAM ODS [48] compliant source, a proprietary relational database, web sites, and a semantic repository. In the second one [26], the middleware enriches a professional search engine[1] to optimize the professional extraction, search, and management of metadata inside raw (unedited) video material.

Finally, we wish to mention that another aim of this article and its structure is to support managers of complex multimedia information management and retrieval systems in the task we have faced: a gradual and seamless enhancement of those systems in order to implement content-based functionalities. To this end, we have structured our work according to different logical entities and have

[1] Fast ESP Search Engine web site http://www.microsoft.com/enterprisesearch/en/us/Fast.aspx.

described our learned lessons, key aspects, and the main difficulties overcome.

This article is structured as follows: Sect. 2 is devoted to the description of the mentioned middleware describing its goal and the features of each of the three layers of which it is composed. Sections 3 and 4 describe the idiosyncrasy and peculiarities of each of the real scenarios where the middleware has been incorporated. Section 5 makes an overview of the most significant related work in the literature. Finally, Sect. 6 includes highlights concerning the future work and the main conclusions of our work.

2 Middleware design

This section provides a brief overview of the middleware that we propose to integrate with conventional information retrieval systems. First of all, in order to contextualize our work, we present a reference model. Then we introduce the architecture of the middleware and summarize the key criteria for the design of each of the layers.

2.1 A reference model for the information retrieval

As already stated, we assume that the implementation of content-based functionalities implies, in different steps of the retrieval process, the management and understanding of the semantics of the domain. Accordingly, we conceive the proposed semantic middleware as the main provider of the semantic information and services required by the different components and applications, existing or to be added, in complex multimedia information retrieval systems.

Our conception of the scope of such systems and the role interpreted by the middleware is aligned with the adaptation made by Larson [22] of the initial architecture proposed by Soergel [45] (see Fig. 1). In order to include the distinction between information retrieval and information browsing proposed by Baeza [3], we have added the "*Browsing Line*". Our work makes continuous references to the lines distinguished in this architecture: *Search Line*, *Storage Line*, and *Browsing Line*.

From the perspective of our work, the semantic middleware that we propose occupies the central block named "Rules of the Game". The arrows exiting this block represent the semantic services that can be provided to the different processes of information retrieval. The services are represented as broken arrows because they are not mandatorily provided. In complex systems, each process may imply one or more modules and a module may take on several processes. Table 1 contains a number of examples of the services that this middleware has been designed to provide. For each example (e.g. query processing support), relevant literature is referenced.

2.2 Three-layered architecture

The architecture proposed for the middleware (see Fig. 2) is based on a classical approach to the development of software applications: data, business logic, and presentation. The three layers are as follows:

- *Semantic middleware knowledge base (SMD KB)*: This layer gathers all the semantic information about the domain of the application.
- *Semantic middleware intelligence engine (SMD IE)*: This layer is made up of a set of interrelated software elements that are able to perform atomic operations over the semantic information gathered in the SMD KB.
- *Semantic middleware gateway (SMD GW)*: This layer is mainly composed of a light-weighted set of interfaces that offer customized services to the different modules of system.

In continuation we provide a more detailed description of each layer and, based on our understanding of each, highlight the key issues required for a correct implementation.

2.2.1 Semantic middleware knowledge base

This is, undoubtedly, the most critical layer of the architecture. Its mission is the modelling and storage of all the information of the domain. It is the key entity to avoiding semantic duplicity.

Among the abstract entities that may shape this layer we highlight the following: document object models, domain representations, notation grammars, terminology mapping resources, dictionaries and thesauri, semantic representation of schemes of information exchange formats, rules for conducting the multimedia indexing, user and context modelling, and policy for the definition of relatedness among documents.

With a view to carrying out an optimum design of a SMD KB, the following issues are critical.

Identification of the domain. The domain is related to the information that is or could be required by the modules of the retrieval system, including the forthcoming ones. It is quite common to try to cover all the domain of the organization, which is to the detriment of other technical criteria such as performance and maintenance.

People in charge of the knowledge base. The selection of the right people in the organization for the design and maintenance of the knowledge base is crucial. Whenever possible, the establishment of a team of at least two knowledge engineers is the best option. The list of skills of the team must include deep and global knowledge of the

Fig. 1 Information retrieval reference model

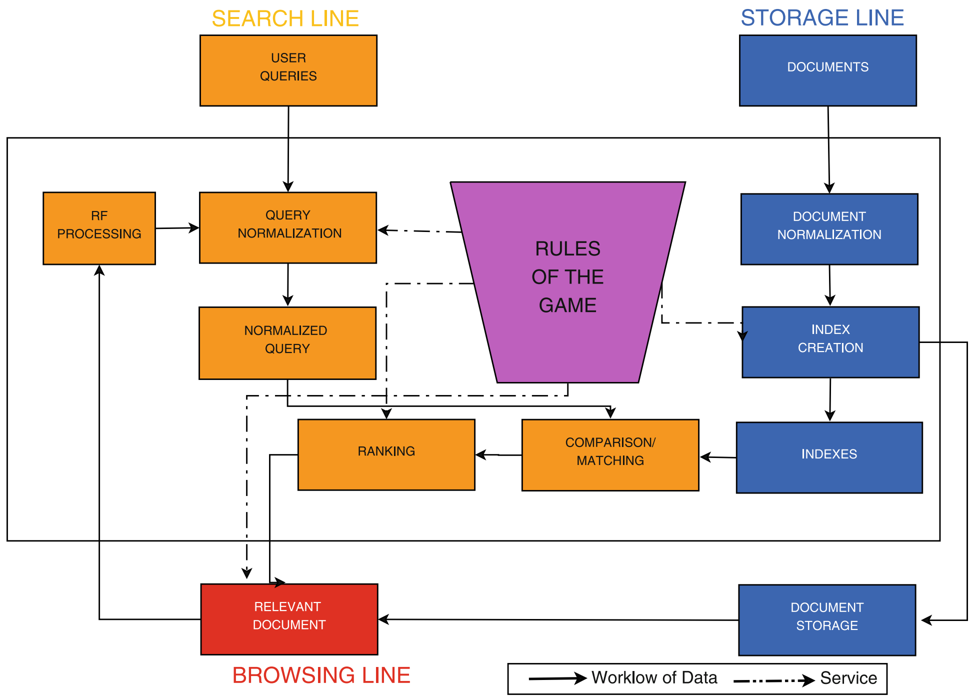

Table 1 Examples of semantic services to be provided in a MIR system

Process	Support service offered by the middleware
Query normalization	Support for query building [2]
	Query processing [1]
	Query expansion [8]
	Query mapping and federation [50]
Index creation	Video indexing [44]
	Text indexing [21]
	Image indexing [51]
	Multimodal indexing [43]
	Support for manual annotation [34]
	Semantic modelling of multimedia standards MPEG-7, DMS-1 [49]
Ranking	Semantic based ranking [41]
	Document organization [19]
Relevant documents	Recommendation systems [53]
	Concept-based visualization [24]
	Semantic visualization techniques [13]
	Relevance feedback techniques [35]

nature of the content handled by the organization and the needs of their users, expertise in semantic formalization, multimedia metadata modelling, technical skills to understand the implications of the design and, depending on the domain, first hand information about the trends and technical road-map of the sector. During the design process a deep relation with experts in semantic techniques in charge of the SMD IE is strongly recommended.

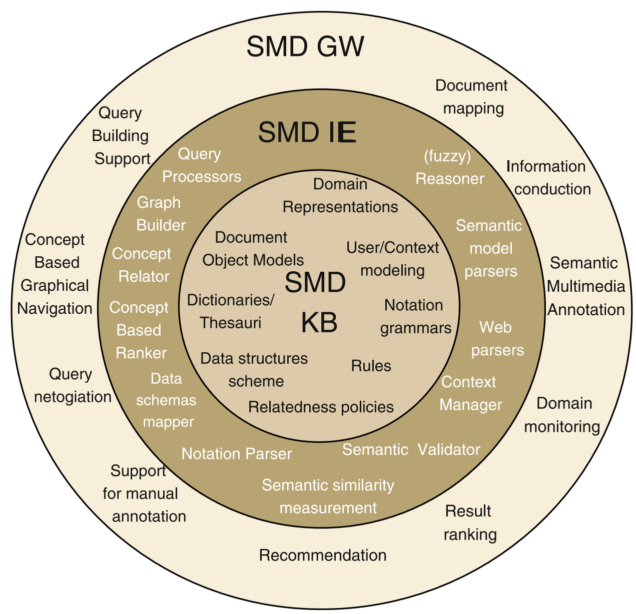

Fig. 2 SMD three layered architecture

Technology of the SMD KB. The nature of the technology to be employed in the knowledge base can be different. We may find, among others, simple thesauri contained in text files, object-oriented schemas or complex and deeply interrelated ontologies. The nature and complexity of the information system to be enhanced is the key factor to selecting the most appropriate technology. In our experience, in the field of the multimedia information retrieval, ontologies are the best option for the implementation of the SMD KB core. This is due to the following reasons: On the one hand, as we will describe in Sect. 5, most of the successful techniques for the implementation of functionalities that make use of the content of the multimedia employ semantic models that are easily reproduced with ontologies. On the other hand, the domain covered by the system is usually composed of different inter-related subdomains (e.g. user context, domain of the multimedia content, internal data formats of the organization). The semantics handled by the ontologies and the ontology mapping facilities are rich enough to support the needs of the SMD KB.

Composition of the knowledge base. The knowledge base can be composed of a set of interrelated or unrelated items (e.g. a set of mapped ontologies, a separated grammar notation, rule files, and so on). Even considering the maintenance cost of interrelated resources, the ideal scenario should avoid isolated semantic resources. As will be stated later, a combined solution of both scenarios, having certain resources isolated and the rest deeply interrelated, is also possible.

Reusing shared knowledge. In many cases information systems are fed by external content, usually coming from a specific sector. The SMD KB should make use, whenever feasible, of the standardisation efforts made by the key agents of that sector or by the scientific community.

Documentation. The generation of the SMD knowledge base must be profusely documented. The meaning of each semantic unit must be unequivocally defined so as to avoid problems in the usage and maintenance of the system. Certain exceptions might be allowed, especially in those cases where part of the SMD KB is automatically enriched by a third party (application, users, etc.).

Update. The update of the SMD module can be caused by external factors (e.g. upgrade in an standard), or internal factors (e.g. statistical information extracted from the users activity). The key issue here is the definition of the right updating procedures and approaches (e.g. supervised update of the knowledge base, consistency checking methodologies, clear definition of the responsibility of each piece of information in the knowledge base, and precise mechanisms to detect the impact of any change on the knowledge base in the SMD behaviour). In our experience, the availability of an stable tool to browse the KB pieces and update them is highly recommended.

2.2.2 *Semantic middleware intelligence engine*

This intermediate layer is in between the SMD KB (a passive layer) and the SMD GW (the layer that acts as the semantic services front-end). This layer is in charge of the semantic interoperability and is responsible for the implementation of the logic to be performed at the top of the zSMD KB from a service agnostic perspective. In accordance with our definition of this layer, the layer itself is composed of a set of software items that perform some specific operations on semantic information. We call these software items processing elements (PE).

Examples of PEs functionalities implemented by the PEs named in Fig. 2 are Inference of new knowledge, query processing, linkage among concepts, building of graphical partial or fully views of the domain, terms translation/mapping, semantic/similarity based ranking algorithms, context managers, format parsers, semantic validation, mapping between data structures, fuzzy reasoning, and notation parsing.

The key issues for the design and implementation of this layer are the following:

Maintainability. In order to facilitate the maintainability of the layer, PEs should implement atomic operations and should ignore the application status. Therefore, PEs are expected to belong to different abstraction levels, having PEs that, while keeping a service independent philosophy, make use of other PEs to carry out their tasks.

Exchange information structures. The definition of the information structures to be shared among the PEs is a key issue. The information structures shared among them (e.g. user profile, semantic graph, and document representation) should be designed to facilitate their interconnection. This implies that the structures should be flexible enough to cover the needs not only of the existing services but also of the forthcoming ones. Our recommendation is to employ an object-oriented approach since it supports the inheritance between the entities, the implementation of new specialized objects for a concrete interface and therefore the maintainability of the whole system. This can result in different implementations: Java objects, XML documents, and so on.

Making use of available resources. The use of the available tools is highly recommended (e.g. ontology reasoners, graph visualization libraries). The Semantic Web community has been very prolific in the development of tools for parsing, inferring and reasoning over semantic structures [47]. If some PEs of the SMD IE employ any external system, the impact of this dependency on the global system should be minimized during the design process. This criterion will lead to a more careful definition of the set of structures employed for the information exchange among PEs, achieving a SMD IE ready for the obsoleteness of certain applications or the appearance of new tools.

PEs network interoperability. Whenever possible, the PEs should be implemented with the same programming language and executed over a common platform. However, if the performance of one of the PEs requires that it be implemented in a different programming language (e.g.

looking for the most efficient reasoner [33]), the SMD IE must provide the communication mechanisms required to ensure the interoperability among them.

Execution synchronization. PEs that carry out tasks of an over-long or unpredictable duration should implement asynchronous communication mechanisms. These PEs can be invoked by other PEs or by the SMD GW and its execution should not block other processing flows.

2.2.3 Semantic middleware gateway

This is the outer layer and is responsible for communications with the rest of the components of the information retrieval and browsing system. It represents the front-end employed by the retrieval system to allow the outsourcing of the semantic services. We call those services the "support processes" (SPs). In Fig. 2, we include, as an example, the SPs we implemented in the scenarios included in this article. Among those services we may find SPs that are provided due to the presence and actions of a final user (online SPs) or SPs that enable functionalities carried out before the user arrives into the system (off-line SPs).

- Regarding the functionalities offered by the online SPs, we highlight the following: recommendation for the query development, query processing functionalities, support to enrich or simplify the manual annotation, facilities for concept-based graphical navigation, terminology adaptations, semantic support for query negotiation among different information sources, result ranking, and document mapping.
- With respect to the off-line SPs this layer may offer functionalities for the following processes: integration of the information provided by the analysis modules during the automatic or semiautomatic indexing of the assets, extraction of new knowledge by applying (fuzzy) reasoning techniques and periodic reporting of potential updates in the representation of the domain in the SMD KB.

We highlight the following key aspects hidden behind this abstract entity:

Flexibility. The technology to be employed should be mainly determined by the requirements of the components of the system which the middleware would interact with. This usually leads to the employment of state of the art networking technology (e.g. SOAP).

PEs invocation. Each SP of the SMD GW should be defined in order to be able to perform parallel invocations of the PEs. This should be done depending on the service required and the configuration parameters on execution time.

Synchronization and status management of each SP. PEs usually perform operations of unpredictable duration, and, especially for operations performed off-line, they may take too long. The SMD GW must have synchronization and failure detection mechanisms for the PEs requests, and each SP must implement procedures to manage and report the status of its task. This allows the integration of the SMD with conventional status monitoring mechanisms of the professional information retrieval system.

Global status management. It is not highly recommended that the SPs provided by the SMD GW handle information about what is happening in the whole multimedia retrieval system. Although it is quite common that a Support Processor of the SMD GW is kept alive and invoked several times during a specific operation (i.e. the automatic annotation performed on the same multimedia asset by multiple analysis modules), it is not recommended. In spite of this, there should exist a third component—either from the MIR system or external—that would handle this status and the signalling to be exchanged with the SMD GW to ensure that the support processor is performed correctly. Otherwise, the complexity integration of the SMD GW would increase significantly and the approach would not fit the philosophy behind the whole middleware architecture.

In the following sections, we include two real deployments of this middleware. Both cover the *Browsing Line* included in Fig. 1. However, they are complementary, since, on the one hand, the first deployment provides a wide range of services for the *Search Line* in order to cover different information sources, while the other implements different services devoted to supporting the *Storage Line*, so as to provide advanced indexing mechanisms of the multimedia assets. Therefore, the combination of the scenarios provides a global overview of the provision of services for the three lines of the reference model for multimedia retrieval.

3 WIDE use case: semantic middleware for multimedia retrieval from multiple sources used by a multidisciplinary team in a car industry domain

The middleware presented here is the key semantic component of the WIDE system [40]. WIDE is a system developed in the context of a collaborative European research project[2] devoted to the retrieval and browsing of very diverse multimedia assets (e.g. images, graphs, patents…) from very different information sources. The domain of the information is the design and testing of cars and engines. The system provides special attention to the differences in terminology, way of self-expression and

[2] WIDE project(IST-2001-34417) http://www.ist-wide.info.

needs of two user communities that work together: engineers and designers.

As can be seen in Fig. 3, the WIDE system, through a platform of search software agents, retrieves information from the following information sources: an SQL relational database of images and documents, an API to perform web searches, the querying interface of a semantic RDF (Resource Definition Framework) repository, and an API to access a system compliant with the ODS (Open Data Services) standard developed by the Association for Standardisation of Automation and Measuring Systems (ASAM) [48]. In order to simplify the complexity of accessing different information sources for the user, a single front-end is offered.

The semantic middleware in WIDE, called Meta-Level, is graphically summarized in Fig. 4. The Support Processes are grouped coherently with the reference model (Fig. 1), and for this deployment are referred to the *Search* and *Browsing* lines. For further technical details about the implementation of the SMD see [27].

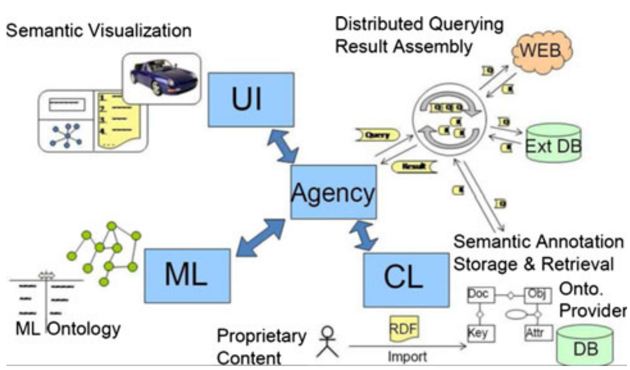

Fig. 3 Architecture of the WIDE system

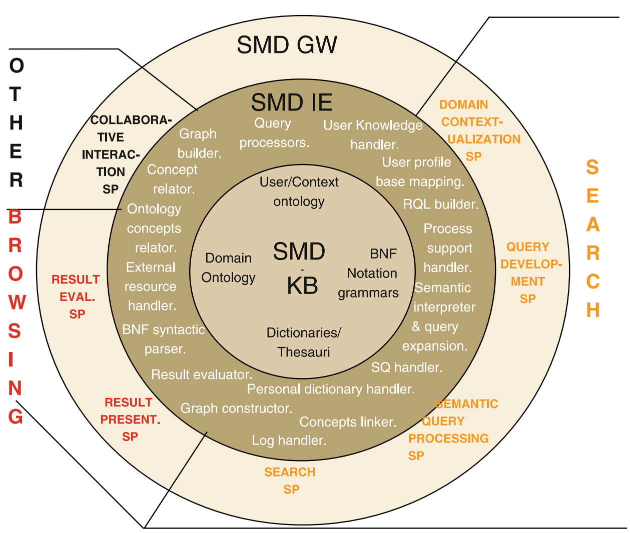

Fig. 4 WIDE SMD

The Meta Level tool is in charge of the semantic operations needed by the search software agents (Agency) and by the aforementioned front-end (UI). As is shown in Fig. 3, the communication with the UI is done through the Agency. The SMD KB layer of the middleware models the different users, their profile, and the tasks they carry out.

In the following paragraphs, we describe how the key design criteria identified have been considered in the implementation of WIDE. The criteria are grouped according to the layer they belong to.

WIDE SMD KB In the following,we provide an overview of the steps followed during the design, implementation, and maintenance of the WIDE SMD KB.

People in charge of the knowledge base: The team in charge of the SMD KB was composed of two engineers, both of them with a long track record of expertise in engineering of car bodies and engines, respectively. Moreover, one of them belonged to standardisation committees in that sector.

Identification of the domain: The domain was initially divided into the following subdomains: users, tasks, and information. As to the users, based on the organization of the company (i.e. nature of the work and information access), more than 20 types of users were initially identified and hierarchically classified. This hierarchy simplified the definition of the terminology of each user type, by applying inheritance to the subtypes with respect to the information available for the supertypes.

With respect to the tasks, following the real workflow of the design and testing processes, the tasks were interrelated using temporal and dependency constraints. The initial number of tasks identified was reduced to a smaller set of tasks (about 35), selecting only those that had certain peculiarities from the search perspective. This was done to avoid performance and maintenance problems derived from the management of tasks that, although intrinsically different, were identical to the perspective of the search requirements.

Finally, the hardest task was the identification and definition of the information domain. The approach most successfully implemented was the following: First of all, a collection of representative multimedia assets were collected. This set was mainly composed of patents from different sources, images of a very diverse nature (from high quality images for inspiration to sketches), 3D objects, graphs, test results, normative for engine testing, and car design. Second, and ignoring the existing metadata of the sources the data came from (i.e. internal database, ODS system, DVD library, and so on), knowledge engineers made a first identification of two lists: set of search criteria and set of relevant targeted pieces of information. After this, those sets were discussed and enriched with representatives of those tasks that had the most demanding search needs. Finally, a coherent object-oriented model was built including the identified pieces of information.

Technology of the SMD KB. The technology employed in the WIDE SMD KB was diverse. First of all, the already identified subdomains were mapped to OWL (Ontology Web Language) [15] ontologies. Seven ontologies were developed. One ontology was devoted to the users, another for the domain of the car industry, three more related to search context (processes, process steps, and tasks) and finally, one developed to reflect the subjective feelings related to the inspiration process of the designers (e.g. "Looking for aggressive animals", "vintage objects"). In total, the system handled more than one thousand interrelated concepts.

Due to the demanding requirements of the online services and the state of the art of the ontology accessing technology during the development phase, the ontologies were parsed and stored in a relational database by a self-developed component. This component performed off-line all the pre-processing required over the ontology to allow efficient usage of the information during the provision of the online services.

Besides the mentioned ontologies, the SMD KB also included a well-known Backus Naur form notation [20] to enable the semi-natural language processing.

Composition of the knowledge base. The main relationships among the concepts of the different subdomains were the following: First of all, the users' types were related to the task the users were involved in, allowing different involvement degrees. Each type of user had a dictionary. This dictionary was mapped to the internal terminology employed in the domain ontology. Then, the different tasks types were interrelated with the concepts of the domain ontology, weighting the relevance of the different concepts for each of the tasks performed. This was done with the goal of first optimizing the query processing (e.g. "Rolls Royce" was linked to the brand of the manufacturer of a car or plane engine depending on the type and context of the user) and second, presenting the results according to the ranking. Thus, the results with a lower semantic distance to the context were prioritized.

The parser of the BNF (Backus-Naur form) notation grammar employed to process the query was also linked with the terms of the information ontology. As a result, the SMD was able to provide query completion support (e.g. If the user typed "Patents about" and waited longer than 2 s, the SMD sent a list of possible items that may be patented to the front-end).

Reusing shared knowledge. The domain of the car and engine design and testing is very broad. For instance, diverse incompatible and very dynamic classifications for the segments of the cars (e.g. station wagon) were identified at the designing stage. Although important sets of standard terminology and schemas (e.g. ODS) were included, most of the information gathered in the KB had to be developed from scratch by the knowledge engineers in order to achieve the project aims.

Update. The object properties of the ontologies were hierarchically defined. The top level of the property hierarchy provided information about the usage of the property in the retrieval system. Therefore, the update procedure for the ontology was done by analysing the different properties of the concept to be updated. Depending on the super-property the property belonged to, an update procedure was defined. The update procedure included guidelines, pre-checks to be carry out or software adaptations that must be required.

WIDE SMD IE In Fig. 4 the most relevant PEs that took part in the SMD IE can be observed. Those PEs, which are described with more detail in [27], perform atomic operations of diverse complexity mainly related with the following functionalities: information extraction (e.g. *Which is the relation between Golf and door?*) and graph generation out of the ontologies (e.g. *Create a graphical view of the relations among the following concepts: patent, engine, and a concrete emission parameter*), parsing of the query according to the BNF grammar, semantic interpretation, and query expansion or enrichment of the queries into different system queries (e.g. *transforming "Pictures about BMW cars" into "IMAGES ABOUT CAR WITH BRAND = BMW"*), transformation of the system queries into queries employed by the search agents (e.g. *"Select pt, mc, c1 FROM pt:$pt mc:$mc… WHERE fp="has_info_about" AND ($pt="Document") AND…"*), the management of the different types of terminologies (e.g. *"the designers employ the term photo while the engineers prefer the term image"*), and the management, ranking, and evaluation of the search results (e.g. *ranking according to the semantic distance between the metadata of the result and the terms employed by the user in the query and the task he or she is performing*).

In the following, we highlight some of the criteria used in the deployment of the WIDE SMD IE, including its relation with different PEs:

Maintainability. The approach followed for the definition of the PEs was the conventional object-oriented software design [37]. For instance, behind the *Graph Constructor PE* there was a set of ten interfaces that generated a graph starting from a set of concepts, but with different input parameters.

Exchange information structures. Reaching a stable definition of the structures of information in WIDE SMD IE was crucial. Some of the software entities most employed and exchanged by the PEs were Node, Graph, Term (semantic or syntactic), TermList, Query, Result, Context, and User.

Making use of available resources. The external resources used by the PEs in the WIDE SMD KB were the RACER reasoner [16], used mainly for consistency check during the off-line processes of the SMD, an OWL API [6], and a combination of JavaCC and JJTree to automatically build the notation grammar parser required by the *BNF Syntactic Paser*, and *Semantic Interpreter and Query Expansion* PEs. The Google Sets functionality [14] was employed by the *External Resource Handler PE* to automatically detect lack of completeness in the SMD KB. Thanks to the thesauri information provided by Google Sets, the system was able to detect that with the query "Sketches of Kia logos", the user was looking for the logo of a car brand even without having Kia identified in the SMD KB as a car brand.

PEs network interoperability. All the PEs in the WIDE SMD IE were either standalone applications remotely invoked or standard Java interfaces.

WIDE SMD GW The online SPs offered by the WIDE SMD GW (see Fig. 4) were implemented in Java RMI and offered as standalone services. SPs were able to provide information on their status at any given time using a list of status codes. The communication of the SPs with the PEs was mainly asynchronous.

The set of SPs covered a wide range of needs in the retrieval process.

- *What to ask:* The *Collaborative Interaction SP* provided terminology mapping support for a tool of the front-end that enabled online communication between the users of the organization. The *Domain Contextualization SP* graphically showed the understanding of the system of the relationship between the terms specified by the user.
- *How to ask:* The *Query Development SP* provided recommendation and validation facilities for the query development.
- *What did the user ask?:* The *Semantic Query Processing SP* and the *Search SP* provided semantic services for the transformation of the user request into a set of results.
- *What was requested?:* The *Result Evaluation SP* and the *Result Presentation SP* were in charge of the semantic ranking of the results coming from different information sources and the concept-based visualization of them.

Regarding the off-line services offered by the WIDE SMD they were related with the following two processes. First of all, the parsing of the ontologies defined by the knowledge engineers in order to store the information in the SQL repository which was part of the SMD KB and was handled by the PEs. Second, the WIDE SMD GW was responsible for the parsing of the BNF grammar into a Java parser that was stored in the SMD KB. Both services were implemented as standalone applications launched by he knowledge engineers on demand.

3.1 Benefits of the middleware to the multimedia retrieval system

In the following paragraphs we summarize the benefits of the incorporation of the semantic middleware to the retrieval system. As has been stated, the benefits are mainly related to the *Search* and *Storage* lines of the reference model.

Support for query development and query validation. Based on a notation grammar the SMD provides support for the construction of semi-natural language queries (e.g. "Patents about doors published before 2007"). The SMD, in accordance with a predefined grammar, validates the syntactical correctness of the query and provides the user with recommendations to facilitate the query completion while he or she is typing. An example of a message sent to the user after the validation is "Missing closing bracket".

Semantic query interpretation and expansion. According to that notation grammar a syntactical interpretation of a well-formed query is performed. Making use of the context information and applying semantic techniques (e.g. reasoning, distance metrics), the SMD provides different versions for the query with various expansion degrees. For instance, the query "Pictures of seats cars" is expanded to "IMAGES ABOUT CAR WITH BRAND = SEAT" and "IMAGES ABOUT SEAT CARS".

Query normalization. The SMD translates the terms of the query into terms that belong to the internal terminology (e.g. pictures is mapped into IMAGES) and the semi-natural language query is transformed into a query expressed in the language employed by the search agents, which is a variation of RQL [17].

Support for Query negotiation. The federation of the query over different search engines is driven by rules and performed by a set of search agents [31]. During this process, these agents require semantic information (e.g. synonyms and term mapping resources, similarity metrics, disambiguation, and so on). The SMD provides them with the semantic resources required during the query negotiation and adaptation phases. For example, the SMD is able to provide a set of terms close to a term queried by the agents according to semantic distance based algorithms.

Results ranking and presentation. The ranking of the results is based on a weighted combination of the analysis of the metadata that the Agency is able to retrieve from the different information sources (e.g. a result extracted from Google not only includes the link but also certain keywords) and the information of the SMD about the context of the user and the task he/she is performing. Regarding the visualization, the SMD is responsible for the construction of the graph sent to the front-end, which then performs a concept-based representation of the results, allowing the user to easily identify the results of the different information sources that provide the results.

Customization of the information presentation. The front-end uses the SMD services to hide the internal terminology from the user at different moments of the interaction. This service enables an automatic translation of the information by employing the terminology of the community the user belongs to and by using his/her personal preferences.

3.2 Meta level evaluation

The evaluation of the Meta Level was performed following a strategy based on three action lines: extraction of performance features, evaluation of the whole WIDE system by end users and evaluation of the opinion of the knowledge engineers regarding the benefits, and drawbacks of the Meta Level.

Regarding the performance of the Meta Level the following evaluation framework was used: a conventional PC with 1Gb of RAM memory and 1.2 GHz where different batch files that enabled the launching of each of the evaluation tests. In that framework, the following Meta Level KB items were installed: a set of seven interrelated ontologies with more than 1,000 concepts and a BNF grammar of more than 550 lines. Regarding the off-line services, the Meta Level was able to infer new knowledge out of the ontologies and parse all the information into the SQL repository in about 5 min and a half, and a java parser was generated for the BNF grammar in less than 1 minute. Concerning the online services, we summarize here some of the most significative aspects:

- The average time required to perform a query expansion, limiting the number of system queries created out of each query to 4 was 1.4 s. Part of this time (0.09 s) was devoted to the validation of the query with respect to the BNF grammar.The number of queries employed in the test was 250.
- The average time used for the transformation of a system query into the RQL queries employed by the Agents Platform was 0.22 s. The number of queries employed in the test were 1,000.
- The average time for the generation of a graph showing the interrelations of a set of 9 concepts was 3.2 s. Two hundred sets were randomly generated from a list of 1,200 concepts, out of which 150 were unknown to the system. The average graph created had 19 concepts and 32 relationships.
- The average requested time to rank a set of 50 results coming from three different information sources was 1.1 s. The number of result sets randomly generated out of real result sets was 200.

All the presented results are just related to the performance of the Meta Level and do not include the communication time required to receive the request or send the answer to the other modules of the system.

Regarding the opinion of the final users, a deep evaluation of the whole WIDE system with more than 20 users was performed in the two companies involved in the project. The evaluation implied the conduction of real experimentation sessions and the fulfillment of opinion questionnaires. Most of the functionalities included in the evaluation were not directly provided by the Meta Level but semantically supported by it (e.g. utility of the results retrieved, query development facilities, and so on). The results of this evaluation showed a globally satisfactory feeling. As a summary, we include some of the most significative results: the time reduction to find the needed information was 25% for engineers and 10% for designers, whereas the graphical representation of the results basing on its nature and their interrelations, and the new opportunity to tackle different information sources at once were positively evaluated.

Regarding the evaluation of the professional users, i.e. knowledge engineers, they highlighted the simplicity of the use and update of the ontologies with respect to the achieved added value. On the other hand, the upgrade and management of the BNF grammar was highlighted as one of the most expensive tasks regarding the maintainability of the Meta Level.

4 RUSHES use case: semantic middleware to enable automatic analysis in large repositories of un-edited audiovisual material in the domain of a broadcaster

The RUSHES deployment of the SMD, also named Metadata Model, [26] is the semantic middleware developed in the multimedia retrieval system of the European project RUSHES[3] [39]. The motivation behind its inclusion in the architecture was to enable the provision of semantic functionalities that were not previously considered in the media asset management (MAM) system of the industrial partners involved in the project. The search engine

[3] RUSHES project(FP6-045189) http://www.rushes-project.eu.

employed in the project was the commercial Enterprise Search Platform (ESP) from Fast, a Microsoft subsidiary.

The global goal of the RUSHES system was to retrieve unedited material—also known as rushes—by integrating automatic and semi-automatic annotation techniques into the retrieval workflow. Special attention was paid to the optimization of the analysis process and to the seamless integration of such annotation in the existing retrieval workflow and systems.

The role of the RUSHES SMD was to semantically support the search by providing the semantic services required by the rest of modules of the system (see Fig. 5). As can be seen in Fig. 6 in accordance with the reference model (Fig. 1), the services provided by the RUSHES SMD were related to the *Search Line*, the *Browsing Line*, and, especially the *Storage Line*. The predominance of the services working for the *Storage Line* was on account of the demanding semantic requirements derived from the annotation process. For further technical details of the implementation of the SMD, see [26].

RUSHES SMD KB The RUSHES SMD KB was mainly composed of a set of axioms used during the fuzzy reasoning and a set of interrelated ontologies that covered the news domain and the technical and descriptive aspects of the multimedia assets. With regard to the key criteria, we highlight the following:

People in charge of the knowledge base. The person in charge of the SMD KB was the archive manager of the broadcaster. His work was supported by a broadcast systems engineer. In the design phase, the cooperation of a multimedia expert was required.

Identification of the domain. The domain of the RUSHES SMD KB was composed of three distinct subdomains. First, the domain of the content (e.g. news content). Second, the domain related to the technical description of the multimedia assets. This domain was related to the services provided by the SMD during the analysis of the video. Finally, a third domain, that of the descriptive understanding of the assets.

Technology of the SMD KB. Following the same criteria as in the WIDE SMD , the language used for the information modelling was OWL-DL. The axioms were expressed following the syntax employed by FIRE, the fuzzy reasoner used [42].

Reusing shared knowledge. For the domain related to the content, the first approach was to integrate an extension of the LSCOM Lite ontology proposed by Neo et al. [30] with the thesauri that the organization was already using for content annotation and classification. However, the final version of the ontology was quite far from the LSCOM lite implementation and much closer to the reality of the organization. For the technical description of the multimedia assets, the SMD KB in RUSHES incorporated an OWL implementation of the detailed A/V profile (DAVP) of MPEG-7 proposed in [4, 5]. Finally, the generic description of the assets was done following the industry design standard SMPTE 380:DMS-1 (Descriptive Metadata Schema) that belongs to the MXF (Multimedia eXchange Format) normative family. This was done by implementing the first OWL ontology for that schema [25].

Composition of the knowledge base. Concerning the composition of the knowledge base, three ontologies were mapped to provide the services while keeping a global perspective. On the one hand, the link of the DMS-1 ontology with the MPEG-7 was done through the temporal decomposition of the profile, where the two ontologies

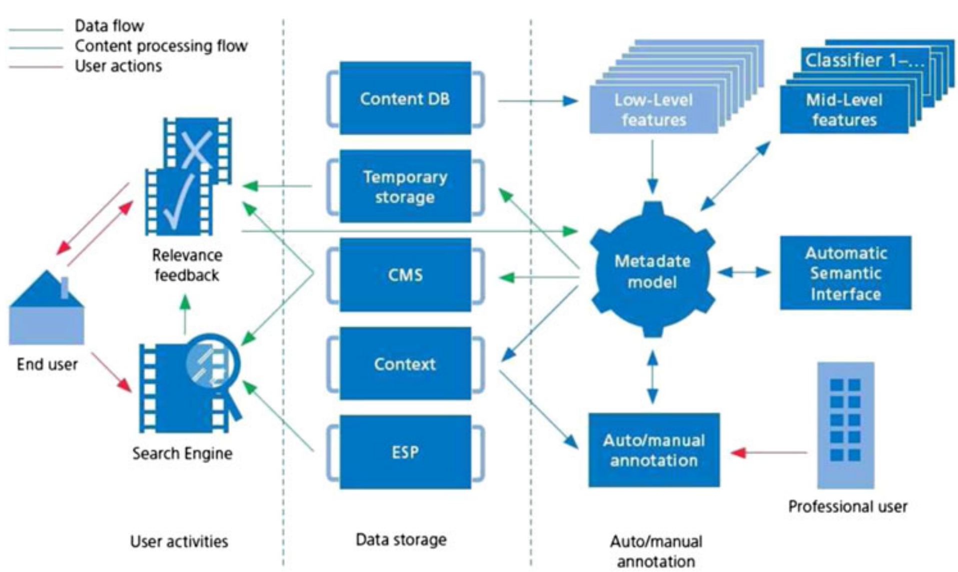

Fig. 5 RUSHES architecture

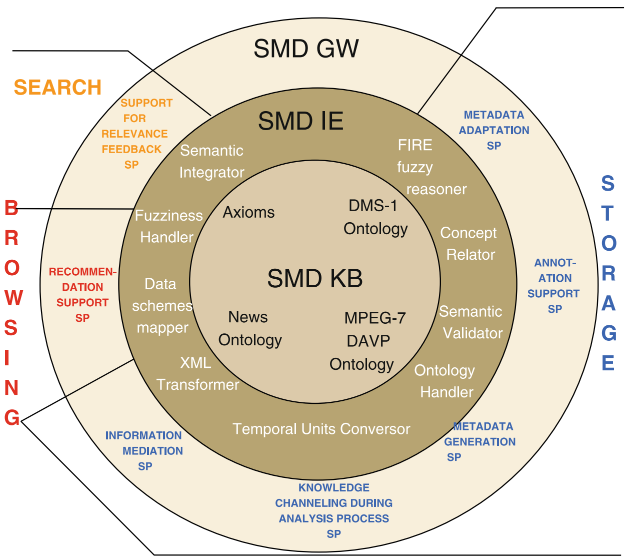

Fig. 6 RUSHES SMD

intersected. On the other hand, the mapping between the DMS-1 ontology and the domain model was realized by linking the dictionaries proposed by the SMPTE 380:DMS-1 and the main concepts of the domain ontology.

Update. Some of the PEs were highly dependent on the implementation of the SMD KB, especially on the DAVP ontology. A file stored the dependencies among the PEs and the ontologies of the SMD-KB. This file provided information about the type and degree of the dependency and was checked before applying any change to the KB.

RUSHES SMD IE RUSHES PEs were mainly related to the effective completion and parsing of the ontologies (based on the Protégé and Jena APIs), the fuzzy reasoning over the information, the building and transformation of the information exchange formats and the parsing of the XML files of the different incoming pieces of information (e.g. DMS-1 compliant metadata coming from the camera, information provided by the shot boundary segmentation module, and so on).

Maintainability. RUSHES PEs were developed following a similar approach to the one defined for WIDE SMD IE. For instance, the *XML Transformer PE* encapsulated more than 20 PEs to handle the XML formats that were parsed and stored in the SMD KB.

Exchange information structures. SMD IE PEs (e.g. *Data schemas mapper*, *Fuzziness Handler*, *Semantic Integrator*) employed mainly three set of structures for information exchange. First, the regular set of structures imposed by the conventional ontology APIs. Second, the specific format for the A-Box and T-Box imposed by the fuzzy inference engine and finally, the format employed for the communication between the components of the whole system. That format was called MeX (Multimedia eXchange Information) and was a customized XML version of the DMS-1 standard. This format groups the annotations according to the nature of the asset. For example, it distinguishes between the annotations referring to the whole asset, a specific scene, a key-frame or region.

Making use of available resources. The *Ontology Handler* and the *Concept Relator*, among other PEs, integrated Protégé and Jena APIs for the SMD KB parsing. The *XML Transformer* employed XML processing APIs for the management of the information structures, and the *FIRE fuzzy reasoner* was based on the FIRE software.

Networking and execution synchronization. All the PEs were implemented in Java accessible through standard java interfaces and provided asynchronous communication mechanisms.

RUSHES SMD GW RUSHES SMD GW SPs were implemented with SOAP. Owing to the significant amount of time required by the set of analysis modules, SMD GW kept a process alive for each video. This process was in charge of the synchronization and communication with all the PEs and the external modules involved during the analysis process. This information was made available to external entities that required it (e.g. control console, user interface components).

The SPs provided by the RUSHES SMD covered different aspects of the content-based retrieval paradigm:

- *Help the system*. The *Metadata Adaptation SP*, the *Knowledge Channeling during the Analysis process SP* and the *Information Mediation SP* were the key SPs to ensure that the pieces of information generated during the analysis process, the metadata provided by entities external to the retrieval engine, and the information required by the different modules (e.g. ingesting module of the search engine, annotation tool), were treated in a semantically coherent way.
- *Help the asset*. The *Metadata Adaptation SP* made use of the information provided through the analysis modules to infer new knowledge. This increased the chances of the rushes material being retrieved.
- *Support the user*. The *Recommendation Support SP*, *Support for Relevance Feedback SP* and the *Annotation Support SP* provided semantic information to external modules and wizards that helped the users. Those tools were, respectively, the recommendation wizard of the user interface, the relevance feedback engine, and the annotation tool provided to complete the existing metadata.

4.1 Benefits of the middleware to the multimedia retrieval system

The integration of the middleware in the retrieval system provided the following functionalities:

Metadata adaptation and information mediation. First of all, the video ingesting and analysis were performed. As a result, diverse annotations belonging to different semantic abstraction levels were extracted and indexed by the search engine. During this process, the SMD carried out parsing processes to convert external data schemes (e.g. DMS-1 metadata [52] coming from a Panasonic camera) or data types (e.g. timestamps) into the internal ones defined in the system.

Knowledge channeling during multimedia analysis. The incorporation of analysis modules to the search engine was the main source of changes from the architectural point of view. An external module was in charge of an execution graph that invoked the different analysis modules. The SMD supported this task by carrying out the channeling of the knowledge during the analysis process. This process involved expert modules (low-level analysis operators, concept detectors, and Bayesian network classifiers) that worked at different stages of the video analysis process. The information generated by some modules was needed by the remaining ones. In particular some modules needed additional pieces of the semantic model in order to perform their analysis. During this process, the SMD was responsible for the persistence and availability of the intermediate information generated (e.g. extracted low-level features or representative key-frames) and the semantic metadata obtained (e.g. a list of faces recognized for each key-frame).

Furthermore, the SMD stored every piece of information generated for each video, preserving its semantic meaning by linking it with the semantic entities gathered in its knowledge base.

Fuzzy reasoning based metadata generation. Once the analysis of the video was finished, the SMD semantic repository was populated with all the information generated by the different operators. This information was related to the structure of the asset (e.g. number of tracks that composed the asset, main shots of the video, representative key-frames, and so on) and with the content (e.g. number of faces present in each frame, type of audio, an essence of vegetation in a shot, and so on). These annotations, often linked to a confidence value, were inferred by the SMD in order to extract new annotations.

Annotation tool, recommendation and relevance feedback. A wizard for self completion of the annotation tool, the recommendation system of the search interface and the relevance feedback modules implemented in the system employed the semantic information modelled in the SMD KB to perform their tasks.

4.2 MDM evaluation

The feasibility and convenience of the deployment of the MDM RUSHES was validated and evaluated as follows. Concerning the feasibility, due to the provision of the services using standardized and well established multiplatform techniques, the MDM was successfully and seamlessly integrated into the RUSHES system. This integration required the interaction with other components such as the FAST commercial ESP search engine, a commercial database, the system interfaces (search and annotation), and the analysis operators, which were developed with different programming languages and executed over different operative systems.

In the following items we summarize some aspects related to the performance of the integrated MDM for a testbed of 70 unedited videos with a total duration of more than 18 hours (the results do not include the time needed for the communication with the rest of the modules of the system):

- During the analysis process the MDM was invoked an average of 1.3 times per analysis operator. However, the waiting time due to the MDM operation for the whole analysis process was, in average, less than the 0.6% of the whole analysis period.
- The average time used by the MDM to generate a MEX file according to the format required by the ESP engine was 4 seconds.
- The generation of new information based on the fuzzy reasoning required as average 0.5 seconds for each analysed video shot.
- The provision of a list of recommendations for the annotations required less than 0.34 seconds.

Regarding suitability, the evaluation of the MDM was mainly carried out through a discussion session with the Broadcast Engineering Department of ETB (Basque Public Broadcaster). The main conclusions are outlined in the following items:

- They corroborated that the middleware on the one hand, allowed a seamless integration with their existing MAM system and on the other hand, it provided the functionality of managing semantic aspects.
- The fact that the MDM did not replace any of the currently available professional solutions for information storage but complemented them was positively considered.
- The channeling of knowledge during the analysis process was understood as a needed functionality according to the progress expected in the Multimedia Analysis processing techniques. However, regarding the MDM some additional features were expected. The

service implemented in the MDM gathered the information coming from the different analysis algorithms, and once all the operators had finished, the information was made available for the rest of the components of the system. However, in many cases (e.g. news), journalists may require the content before this process ends. It would be very useful to be able to provide partial results of the analysis (e.g. shot boundary information), even if the whole process is not yet finished.

- Their lack of previous expertise about the semantic technologies employed within MDM IE layer was considered as an startup barrier. However, it was also understood that the intermediate layer (MDM IE) was to be upgraded only on a long-term basis.

The results of the global system evaluation can be found in [36].

5 Related work

Table 1 included in Sect. 2.1 summarizes significant works devoted to the enhancement of different steps of the content-based retrieval process. However, there are few reported initiatives that aim to tackle the semantic needs that arise during that retrieval workflow; from a centralized perspective. Among these works, in this section we highlight those that have something in common: they propose a model, a layer or an architecture to semantically support more than one of the processes that enable the content-based multimedia information retrieval.

Meghini et al. [28] is a most remarkable contribution as far as the literature that handles the problem from a generic perspective is concerned. This theoretical approach is related to the integration of methods and techniques for Multimedia Information Retrieval (MIR) by including a conceptual model that encompasses in a unified and coherent perspective, the many efforts that are being produced under the label of MIR. It is a top-down approach that includes both formal and informal knowledge. The logic adopted is the Description Logics (DL). Our work shares the motivation of Meghini et al. However, our approach is a bottom-up which bearing in mind the current status of the MIR systems and their workflows, aims to provide a generic and flexible framework to integrate the content-based paradigm.

Candela et al. [10] also highlight the lack of standards for implementing the mechanisms to access semantic services in a retrieval workflow. Their solution is based on the Information Mediator Layer, which unifies the access of the information with higher level services. This approach enables the provision of semantic services. The main difference with our work is that the working unit employed by their approach is not the retrieval system of an organization but an information source, and accordingly they establish a layer for each one of the information sources.

The working unit of the Intelligent Media Framework [9] is neither the system nor the information source but each piece of knowledge itself. Their approach relies on the existence of "Knowledge Content Objects". Taking for granted that this intelligence (e.g. processing capacity) exists, their work covers aspects such as the storage of media, knowledge models, metadata relevant for the live staging process, providing services for the creation, management and delivery of intelligent media assets and so forth. The need for this intelligence in the assets is precisely the main difference with our work.

In [18], Kerschberg and Weishar also propose a three-layered architecture for information retrieval over external and internal sources. It is based on the conceptual modelling of the information sources through an Intelligent Thesaurus. Each of the three layers provides services to external modules. Besides this disparity, the main difference is that their work involves replicating all the information to be searched according to a specific format in an internal component.

The work of Castells [11] employs an ontology-based scheme that integrates the semi-automatic annotation, search, and retrieval of documents. The main difference is that this work is a very specific particularization of information retrieval, mainly focused on the Semantic Web environment, which is outside the field of our work.

Finally, the work of Schallauer et al. [38] constitutes a remarkable contribution in terms of the MPEG-7 standard. They propose a complete open MIR system designed to tackle the difficulties and peculiarities of the multimedia indexing. Therefore, their approach not only covers aspects related to the content analysis but also a search component, a backed infrastructure for the storage, and a manual annotation tool. This work shares the objective of our work, but it is significantly different to our approach, since it does not complement a system, but implements a new one, replacing the existing technology.

6 Conclusions and future work

In this article we have shown the noteworthiness of content-based functionalities on the top of the existing multimedia search and retrieval systems. First of all, we have presented a reference model for the retrieval process, which distinguishes three lines, and, where the provision of what we call semantic services is outsourced to a sole module, the semantic middleware.We have proposed a generic architecture to implement that middleware of which its main contributions are

- It enables the incorporation of content-based features throughout the retrieval process (*Storage*, *Search*, and *Browsing* lines).
- It avoids semantic redundancy by assembling the modelling of the domain in a sole component.
- It facilitates the maintainability, by allowing the gradual incorporation of content-based features.
- It favours a seamless integration with the existing technologies.
- It provides a single internal semantic representation that facilitates semantic interoperability with external entities.

Moreover,based on the experience acquired from applying the architecture, we have included a set of key issues for the correct deployment of each of the layers that compose the middleware.

The feasibility of the proposed architecture has been shown by describing its deployment in two real scenarios, covering the three lines of the reference model. For each scenario, we have described the solutions adopted for the key issues. Although we have not had the chance to deploy the middleware in a real scenario where complex services are simultaneously offered to the search, storage, and browsing lines, we do not expect any problem in the deployment of the SMD in such scenario, mainly because the services related to the storage line are performed in advance to the interaction of the user and the retrieval system (off-line). So, regarding the performance issues, the PEs that implement the most time-consuming operations of those services can be deployed in different machines from the ones that run the services employed by the final user.

In summary, we consider our work to be a valuable contribution for people in charge of complex and conventional retrieval systems and who must face a gradual enhancement of these with content-based functionalities.

As to future work, we aim to explore the usage of the semantic middleware to automatically generate annotations of the multimedia assets. We started this work by applying fuzzy reasoning in the RUSHES scenario. In the future, we intend to increase the cooperation between middleware and analysis modules, establishing an iterative communication. The main idea is to employ the knowledge gathered by the middleware to guide the analysis process. The preliminary steps of this work can be found in [32].

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