Knowledge Organization Systems for the Representation of Multimedia Resources on the Web: A Comparative Analysis

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Abstract: The lack of standardization in the production, organization and dissemination of information in documentation centers and institutions alike, as a result from the digitization of collections and their availability on the internet has called for integration efforts. The sheer availability of multimedia content has fostered the development of many distinct and, most of the time, independent metadata standards for its description. This study aims at presenting and comparing the existing standards of metadata, vocabularies and ontologies for multimedia annotation and also tries to offer a synthetic overview of its main strengths and weaknesses, aiding efforts for semantic integration and enhancing the findability of available multimedia resources on the web. We also aim at unveiling the characteristics that could, should and are perhaps not being highlighted in the characterization of multimedia resources.

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1.0 Introduction

The production, organization and dissemination of information in institutions such as archives, libraries, museums and documentation centers has undergone several challenges, because of the facilities introduced by information and communication technologies. The challenges lie mainly in the lack of standardization of the production format and consumption of information associated with its users, which is a result of the digitization of collections and their availability on the internet. Applying web technologies to a variety of domains and specific areas are drives of innovation, resulting in the increasing number of audiovisual content. The areas of application encompass business, science, government, media, culture, among others (Domingue et al. 2011). Another change that increases the production of digital content is the multiplication of electronic devices (scanners, tablets, digital cameras, camcorders, telephones and smart TVs) integrated to the web, which allow the consumption and management of multimedia content. Such growth has become chaotic without the proper support of technologies for storage, organization and retrieval of information.

The nature of multimedia is complex, as it includes various types of objects, such as videos, texts, sounds, images, 3D models, among others—each of them possibly being segmented into other media fragments of the same or other nature (e.g., video segments can become images). Multimedia applications are many (Adjeroh and Nwosu 1997; Domingue et al. 2011) in the scope of distance education, digital libraries, health (telemedicine, medical image databases), entertainment (databases on-demand video, interactive TV), business (video conferencing, e-commerce), cultural heritage (digital collections organized in databases from museums and other institutions responsible for the custody and dissemination of works of art and historical documents), among others.

Research has been done in the fields of information sciences, aiming at the problem of excessive information and its organization, with the aim of improving the effectiveness of information retrieval systems. In this perspective, there are attempts to capture and represent semantics in data records, as:

i) The semantic web stack and the linked open data (LOD), offering methodologies, technologies and metadata standards to increase the scope of interoperability and the full integration of heterogeneous information systems (Berners-Lee et al. 2001; Berners-Lee 2006; Bizer et al. 2011; Domingue et al. 2011);
ii) Instruments for the semantic representation of concepts and relationships (knowledge organization systems) aiming at addressing issues related to the interoperability of systems and databases, as well as the difficulties inherent in the manipulation of natural language, such as polysemy and synonymy. Examples are ontologies (Gruber 1993; Guarino 1995; Smith 2004; Almeida 2013; Soergel 2017) and controlled vocabularies (Dahlberg 1978; NISO 2005; Silva et al. 2008; Junior et al. 2017); and
iii) Ontological and conceptual reference models that serve as conceptual templates for a document's contents and also to the process of searching and retrieving information in digital contexts. Examples are *FRBR—Functional Requirements for Bibliographic Records* (IFLA 2009); *CIDOC CRM—International Committee for Documentation/Conceptual Reference Model* (Le Boeuf 2018) and its extensions for documenting digital objects in cultural heritage, CRMdig (Doerr and Theodoridou 2011; Doerr et al. 2016) and Linked.Art (Fink 2018); M3O—Multimedia Metadata Ontology (Saathoff and Scherp 2010); and EDM—Europeana Data Model (Europeana 2017).

"Ontology" is a multidisciplinar concept that derives from philosophy, linguistics, library science, artificial intelligence, software engineering, logic, just to name a few. Ontologies are relevant as instruments of knowledge organization that focuses especially on the analysis of entities/concepts and relationships in a domain. In this sense, the ontologies studied in this paper are expressions of knowledge organization systems (Almeida 2013; Soergel 2017; Hjørland 2003; Hodge 2000) considered as (Hodge, 2000, 3) "the heart of every library, museum and archive," and "mechanisms of information organization." Hjørland (2003) states that the organization of knowledge is linked to the analysis of the concepts and relationships of a knowledge domain, with the consequent synthesis of a knowledge organization system (KOS). According to Hodge (2000), the term KOS was proposed in 1998 by the Networked Knowledge Organization Systems Working Group to encompass classification systems, subject headings, authority files, semantic networks and ontologies.

Hjørland (2003) states that for the library and information science (LIS) community, knowledge organization is core to the organization of bibliographic record information, including: i) association, through the generation of relationships; ii) representation, generating access points and indexes in cataloging and indexing processes; iii) classification, promoting placement and ordering for documents; and, iv) categorization, generating categories schemas. Originally, these representations had a primary focus on books, but today, in multimedia production contexts, descriptions of diverse media such as audio, videos, graphic objects, databases, websites and other media are paramount. Thus, ontologies seen as KOS can be addressed, for example, for the organization and control of the terminology used in metadata for various media and to assist users in producing more systematic and consistent descriptions using explicit knowledge about a domain. This model is referred to in the literature as a semantic annotation of documents (Uren et al. 2006; Bürger et al. 2010; Domingue et al. 2011; Silva and Souza 2014), which make them "intelligent" in order to provide knowledge about the content, making it possible for the machine to process. For example, in order to avoid ambiguity about the word "Paris" from a text, a semantic annotation could relate it to an ontology element that identified it in the "city" category as well as to associate it with the "France" instance belonging to the category "countries." Thus, "Paris" could not be referred to otherwise except as a French city.

In recent years, there has been a significant growth of semantically related and distributed data on the web. In this regard, the World Wide Web Consortium (W3C) have recommended the use of metadata standards to describe and represent multimedia resources, enabling the expansion of access points and improving the management, organization and retrieval of digital collections. However, the relationship between multimedia and the web of data still lacks advanced studies aimed at efficient technologies for generating, exposing, discovering and consuming multimedia, semantically linked web resources (Schandl et al. 2012).

Metadata creation is the most commonly used way to semantically enrich documents (Velluci 1998; Gilliland-Swetland 2016; Svenonius 2000; Taylor 2004; Abbas 2010) aiming at facilitating the search for information resources. In the scope of the semantic web, the metadata is aggregated through the so-called markup languages and the semantic web stack. At its core, XML (eXtensible Markup Language), define tags or markings that are added to the data to indicate the meaning of the fields. XML alone is not enough to allow the correct interpretation of information by computer systems, since such systems cannot infer, through markings, the contextual meaning of data. Descriptive frameworks have been proposed to offer more precise meaning to the information that characterizes a given resource, such as RDF (Resource Description Framework), RDF Schema and OWL (Ontology Web Language). Such technologies allow machines to interpret markings with well defined semantics to ensure, for example, that the annotator and the consumer share the same meaning in regard to a resource.

Traditionally, the knowledge embedded in textual documents is managed through adding metadata (e.g., keywords, authorship, publication date, summary, etc.). However, the representation of multimedia documents that refers to several types of objects has a much more complex structure, since it deals with aspects as the spatial relations between elements of interest within the media content; with temporal relations in the occurrence of events within a period of time; with technical attributes of low-level content (colors, textures, sound tones, description of melody); and with high-level semantic features such as gender classification or representation of information about people portrayed in the media, to name a few.

The need to include enhanced metadata to textual resources aims at describing multimedia content, especially on the web. To this end, communities of researchers and policymakers joined efforts to provide a common metadata framework for intelligent media applications. These are the cases of the W3C and the International Organization for Standardization/International Electrotechnical Commission (ISO/IEC).

The digital library community uses metadata as an aid in cataloging and retrieving information in large collections of documents. The Dublin Core standard (Abbas 2010) is commonly used in the community with its fifteen specific metadata elements and qualifiers, intended to describe primarily provenance, format, language, copyright and physical data. According to Hunter and Iannella (1998), the Dublin Core was designed for the production of metadata for textual documents. Although much effort has been made to propose solutions for extending the elements into the context of non-textual documents, the emphasis is usually on the use of sub-elements and specific schemes (the standard qualifiers) for audiovisual data. In addition, such data are addressed more to the bibliographic description than to the documentary content.

The metadata standard more commonly used for describing multimedia content is MPEG-7 ISO/IEC (Nack and Lindsay 1999a; Nack and Lindsay 1999b; Salembier 2001; Salembier and Smith 2001; Chang et al. 2001; Martínez et al. 2002; Martínez 2002), formally named Multimedia Content Description Interface. MPEG-7 originated in 1998 and in 2001 became the ISO/IEC 15938, an international standard under the responsibility of the Moving Picture Experts Group. The standard provides a rich vocabulary of multimedia content (audio-visual, in particular), including low-level descriptors, extracted from the media itself and high-level descriptors intended for the semantic description of multimedia content, consisting of a combination of audio visual and textual data (Salembier and Smith 2001).

The MPEG-7 descriptors are organized into schemas that include different functional areas such as content management, structural aspects of content (spatial, temporal or spatial-temporal components), semantic aspects of content, low-level features involving visual and audio content, navigation and access, user interaction and collection of objects. The MPEG-7 XML schema set defines 1,182 elements, 417 attributes and 377 complex types. According to Garcia and Celma (2005), the management of the standard becomes difficult due to the size and complexity in specifying its elements. In addition, the semantics involved in most of its constructs is implicit in the fact that it is a restricted use of XML (a syntax-based language).

The MPEG-7 ISO standard encompasses a lot of efforts in the proposition of a common interface to describe multimedia material reflecting information about the content. However, in spite of being a standard of description recommended by the multimedia community, it has limitations regarding to semantics because it is based on the XML Schema format (Van Ossenbruggen et al. 2004; Nack et al.

2005; Arndt et al. 2009; Nixon et al. 2011). Because of these limitations, the communities of digital library, knowledge representation and artificial intelligence—that usually interpret, manipulate and generate multimedia files, especially in the web—have participated intensively in research projects focused on models and technologies for description and indexing of documents—not necessarily textual but also involving videos, images and audios. The goal is to go beyond current metadata standards (Dublin Core, MPEG-7, among others) with the adoption of ontologies for describing multimedia documents based on the consolidated characteristics derived from these standards (Silva and Souza, 2014).

During the last decades, a number of initiatives have emerged in the production of ontologies represented in RDF/OWL to describe multimedia data (Silva and Souza, 2014; Lemos and Souza 2019), whose efforts aimed at transforming metadata standards such as MPEG-7 in formats similar to ontologies. In this perspective, this article contributes to the proposal of a systematic study on initiatives of metadata standards, vocabularies, models and ontologies aimed at the domain of multimedia description, and it presents a ranking of ontologies based on a comparative analysis and a careful evaluation on dimensions concerning the reuse of knowledge resources available in the web of data.

The main contribution of this paper is to shed light to the existing standards (including metadata, vocabularies and ontologies) addressed to the description of multimedia documents for information sciences researchers. It offers a contrastive analysis of several proposals and standards that seek to identify all the characteristics that should be described for better retrieval of multimedia resources, especially in the context of the web. We do not know of any research that presents it so broadly. The relevance of the comparison of proposals and standards is the need for semantic integration and global availability of multimedia resources in the network and also to unveil the characteristics that could, should and are not being described for characterization of this type of resource, reflected in the selection decisions for the reuse of available knowledge resources.

2.0 Methodology

We have utilized methods and techniques aimed at the identification, selection and elaboration of an instrument for comparing the multimedia standards. For that, it was necessary to review the literature on the area of ontology engineering in order to find a proper methodological guide, tested and validated in different domains and areas. We have adopted the NeOn Methodology (Suárez-Figueroa et al. 2012), derived from methodological frameworks widely accepted in mature areas such as software engineering and knowledge engineering.

The NeOn methodology covers scenarios that suggest a series of customizable steps for the development of web ontologies. Suárez-Figueroa et al. (2012) propose the reuse of available knowledge resources to model the necessary knowledge of a domain; searching, selecting and analyzing the available resources to promote integration. An ontological resource includes, for example, existing ontologies or parts of them. They also aim to inspect the content and granularity of ontologies in order to verify the degree of coverage of the requirements specified in the phase of knowledge acquisition. Some functional aspects such as names derived from standards (metadata standards, for example) and well-structured taxonomies (Gómez-Pérez 1999; Arndt et al. 2009; Troncy et al. 2007; Saathoff and Scherp 2010) may facilitate the extraction of the knowledge required for reuse. Another important factor for the feasibility of the process of alignment and combination of resources is the language to be used for the implementation of the candidate ontologies. It needs to be compatible with the model that is being built to be sufficiently expressive in the characterization of the domain conceptualization. Accordingly, the reuse of ontological resources is considered highly positive, and includes the reuse of possible ontological resources to build or improve an ontology network.

The methodological steps followed were: i) search for candidate ontologies for documentary and content analysis, preferably available in semantic web repositories; and, ii) conduct contrastive analysis between the ontological resources selected in (i) from predefined criteria in the research.

The methodological process, as well as the description of its methods and techniques, is shown in the following sections: Section 2.1 presents the method used for the procedure of acquiring knowledge about the domain of multimedia annotation to define the functional requirements useful for the next steps of the research; Section 2.2 presents the method used to identify and select ontologies for multimedia annotation in the literature and in specific repositories; and Section 2.3 shows the methodology to support the analysis and comparison of the selected ontologies.

2.1 Acquisition of knowledge about the domain of multimedia annotation: definition of functional requirements

As a first step, we proceeded with a search through available sources in the domain, including standards, articles and libraries for describing multimedia documents. The MPEG-7 and Dublin Core ISO standards were selected as reference material for acquiring knowledge about the domain. We know from previous work (Silva and Souza 2014) that most of the ontologies for multimedia annotation are constructed following those standards. To survey MPEG-7 standard audiovisual schemes and descriptors, two reference materials were used, namely: i) the specification of visual[1] and audio[2] descriptors; and, ii) ISO/IEC JTC1/SC29/WG11N6828,[3] which specifies the requirements of the standard. Thus, the multimedia parameter elements were determined by the composition of MPEG-7 descriptors, description schemes and Dublin Core[4] elements.

A set of functional requirements (120, cf. Silva 2014, 330-338) was organized after the domain analysis and served as a basis to identify, analyze and compare ontologies for multimedia description. Functional requirements are best practices from the area of software engineering that have been adapted in the area of ontology engineering (Suárez-Figueroa et al. 2012) to aid the content specifications of a domain of knowledge in particular, obtaining, as a result, terminologies to be incorporated in an ontology. In the specific case of the domain of multimedia description, a knowledge about media could be represented, for example, in the following statements: "a GIF is a type of image format;" "a 3D format is a subclass of media format;" and, as terminology one could obtain from an MPEG-7 standard convention: "mpeg7: Content" and "mpeg7: FileFormat." The organization of these requirements were made in three categories of metadata types (according to our literary warranties), namely: i) content-independent metadata; ii) content-dependent metadata; and, iii) descriptive content metadata.

The category (i) content-independent metadata (thirty-two requirements) aims at the management and administration of information resources and was organized into four types of description, namely:

i) Creation and production of the media;
ii) Classification of the media;
iii) Media information; and,
iv) Use of the media

In (i), we have characteristics involving the creation of media content and associated resources; in (ii), we have features regarding classification of audiovisual materials, such as gender, subject, purpose, language, besides age classification, orientation for parents and subjective evaluation; in (iii), we have the characteristics focused on the storage media, including format, compression and encoding of audiovisual content; and, in (iv), those related to copyright, registration, availability and information on costs (if applied).

The category (ii) content-dependent metadata (fourty-four requirements) has been organized into subcategories:

i) Visual metadata; and,
ii) Audio metadata

Both of which are considered low-level and usually computational algorithms extract their contents automatically. Visual metadata encompassed features: basic structures, color, texture, shape, movement, location and face recognition. The audio metadata included the following characteristics: spectral base, spectral timbre, temporal timbre, signal parametric and basic spectrum.

The category (iii) descriptive content metadata (forty-four requirements) is characterized by associating media entities with real-world entities and has been organized into the following subcategories:

i) Media segments;
ii) Content semantics;
iii) Content customization; an,
iv) High-level features involving audio

In (i), there are characteristics related to the content structure in terms of video (segmentation), static image and audio segments; in (ii), there are features involving objects, events and notions of the real world that can be abstracted from the multimedia content; in (iii), they add characteristics of modes of personalization of multimedia content in order to facilitate navigation, access and interaction of users in relation to the consumption of content; and, in (iv), there are features aimed at covering specific knowledge domains involving audio.

2.2 Ontologies identification and selection

The second step was to identify ontologies by doing a survey in the literature and searches in semantic web repositories. The criterion used for the selection of ontologies in the literature was the presence of the term "multimedia" in the description. Another principle adopted for the selection criterion was to follow relevant guidelines in the literature and recommended by the MPEG-7 metadata standard in the aspect of multimedia description, involving:

i) Descriptions in the subject expressing the semantics transmitted;
ii) Structural descriptions allowing the decomposition and location of content parts; and,
iii) Low-level descriptions covering audio and visual characteristics

For the identification and selection of ontologies, the NeOn guide recommends the use of search engines for the retrieval of ontologies in semantic web repositories. In this sense, the search engines selected were Watson[5] and Swoogle,[6] because they were well evaluated in projects and user validations. The content analysis of the identified ontologies was performed through the Protégé 4.3 editor.[7] The search in the literature and in web repositories yielded seventeen ontologies for multimedia annotation as candidates for the analysis. After refining the process, nine ontologies were selected. They are briefly described below.

- The Media Ontology (Stegmaier et al. 2009) was proposed in 2009 by the W3C Media Annotation Working Group. The ontology was constructed using standards for ontology engineering methodologies and its goal was to define a set of central annotation properties to describe multimedia content, along with a set of mappings between the main metadata standards in use.
- The M3 Multimedia (Atemezing 2011) is part of a comprehensive ontology called M3 Ontology Network, the result of a Spanish research project called Buscamedia. The project aims to create a semantic search engine for multimedia resources in the areas of semantics, audiovisual production and media distribution. The ontology models multimedia information for various domains and languages.
- The Multimedia Metadata Ontology (M3O) (Saathoff and Scherp 2010) was proposed in 2010 as a comprehensive model for representing metadata for multimedia description, including model combinations and metadata standards for semantically describing multimedia document presentations.
- The Boemie project (Bootstrapping Ontology Evolution with Multimedia Information) (Dasiopoulou et al. 2008) started in 2006, and a final report was published in 2008. It aimed the development of ontologies for multimedia annotation in specific domains for the purpose of representing multimedia semantics within specific application scenarios.
- The Core Ontology for Multimedia (COMM) (Arndt et al. 2009) was developed in 2007 by a group of renowned researchers in the areas of multimedia, digital libraries and the semantic web. The main purpose of this ontology is to provide a fundamental conceptualization that can cover in a generic way a specific domain that deals with multimedia content.
- The MPEG-7 MDS (Valkanas et al. 2007) ontology was developed in 2006 within the Polysema project. The project proposed an adequate infrastructure for semantic management and processing of multimedia content with the use of ontologies and metadata standards in interactive environments, especially digital TV services and video annotation tools.
- The MPEG-7 ontology (Hunter 2001) was proposed in 2001 within the Harmony International Digital Library project. The proposal was to manually translate the MPEG-7 standard into RDF and RDFS and later into OWL in order to link semantic descriptions to specific domain ontologies.
- The SmartWeb project (Vembu et al. 2006) was conducted between the years 2004 and 2007, involving a set of ontologies to support mobile, multimodal and intelligent systems that would be able to respond to queries on various domains on the web.
- Last, but not least, the Rhizomik ontology (Garcia and Celma 2005) was developed within the ReDeFer project in 2005 with the purpose of producing ontologies based on the MPEG-7 standard for integration with existing multimedia metadata initiatives. The project took a different approach from the proposals for manual translation of parts of the MPEG-7 standard, aiming at a complete and automatic translation of MPEG-7 schemes into OWL.

2.3 Analysis and comparison of the ontologies

The third step was to analyze and compare ontologies for multimedia annotation based on a careful inspection of their characteristics. We have used a weighted average statistical formula aiming at ranking the candidate ontologies for reuse, involving a set of metrics. The possible values are measurements of each criterion according to rules predetermined by the ontologist. The possible weights range from one to ten, according to the degree of importance given to the criterion by the ontologist. The guide assigns the symbols (+) and (-) to the weights to consider the positive or negative influence of a given criterion on the resulting ranking score. It should be noted that the weights, as well as the established rules for the criteria, are one of the contributions of this paper, and these points are further discussed in the generalization of the methodology. The criteria for analyzing and evaluating the ontologies are mostly derived from the methodological guide NeOn (Suárez-Figueroa et al. 2012), which originated from use cases in several design experiments involving the development and reuse of ontologies. The organization of these criteria occurred in four dimensions, as follows:

i) Resource Reuse Effort: estimation of costs related to time and economy required to reuse the evaluated ontology;
ii) Resource Understandability Effort: estimation of effort required to understand the content of the evaluated ontology;
iii) Resource Integration Effort: estimation of efforts undertaken to integrate the evaluated ontology to the new ontology that is being built; and,
iv) Resource Reliability: analysis of the performance of the ontology evaluated against aspects of semantic treatment in declarations (e.g., axioms present, knowledge resources used), evaluation (e.g., available tests) and renowned projects that make use of them

Table 1 presents the seventeen criteria in their respective dimensions, with their measurement forms (possible values column) and indicated weights.

Four new criteria were designed and adapted for the present research. They were added to the existing ones to rank ontologies regarding its reuse. These were:

i) Number of functional requirements covered;
ii) Use of available knowledge resources;
iii) Axioms identified in the compatibilized terminology; and,
iv) Annotations identified in the compatibilized terminology

The criterion "number of functional requirements covered" was classified in the "integration effort" dimension, because it refers to the coverage of multimedia features satisfied by the candidate ontologies to be reused. For the determination of the numerical value for this criterion, we considered the intersection of the elements present in the set of functional requirements determined in the research with the set of elements present in the terminology of the analyzed ontologies. As one of the main contributions of this research, the fact of identifying characteristics that can (and should) be described for a better description of multimedia resources justifies the indication of the weight ten for this criterion.

The criterion "use of available knowledge resources" evaluates whether the candidate ontology has made use of available ontological and non-ontological resources (e.g. foundational ontologies) that promote, for example, a standard and consensual knowledge of the domain and/or a rationale based on philosophical and linguistic theories that approaches a given portion of reality. High-level ontologies have been called "foundational ontologies," considered to be philosophically well-used and domain-independent categories systems (Almeida 2013; Soergel 2017; Guizzardi and Wagner 2010). For example, the Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) is a conceptual ontology based on cognitive, philosophical and linguistic aspects (Masolo et al. 2003). In this sense, a foundational ontology with its formal system of categories brings semantic benefits when it clarifies the intended meaning of the terms, thus supporting the integration of a multimedia ontology with specific domain ontologies. These characteristics favor the reliability of the candidate ontology in addition to the semantic aspects that support interoperability issues in the web. As an important discriminating factor, weight eight was chosen for this criterion.

The criterion "axioms identified in the compatibilized terminology" evaluates the presence of semantic restrictions involving the classes and properties of the compatibilized terminology. It was fitted in the dimension "reliability," because the formal statements support the interpretation by a machine through logical inferences and also allow support for interoperability issues on the web. Two reasons led to the attribution of weight six to this criterion. The first reason is that the adequacy of the axioms against the multimedia requirements was not considered in the ontology analysis stage (a specialist in the domain would have to be followed up, which did not happen). Thus, even knowing the importance of its existence in the compatibilized ontological elements (being able to have a greater weight), its veracity was not evaluated, only identified. The second reason lies in the fact that there are cases in which the ontologies are made available in the repositories without axioms or with few axioms.

The criterion "annotations identified in the compatibilized terminology" evaluates the presence of relevant information about a compatible element in the candidate ontology, favoring the understanding about its nature. An annotation may be present in a format, for example, of textual definition to which Smith (2013) refers as a sentence with necessary and sufficient conditions for the definition of the nature of a concept. In this sense, it is justified to classify this in the dimension "effort for understanding." Finally, weight five was determined for this criterion because of the comments presented without rules and standardization in the analyzed sample.

Ontologies were mostly represented in OWL and analyzed using the Protégé 4.3 ontology editor. The elements served as a methodological tool for the analysis of functional requirements in relation to the candidate ontologies for reuse.

The functional requirements analysis frameworks were organized by ontology and modularized by the categories of metadata types listed in the research. In the design of the analysis structures, the functional requirements and their descriptions were arranged in lines and the ontological elements inspected were placed in columns formatted as classes, properties, instances and axioms. Classes are hierarchical structures with generic/specific and whole/part relations, responsible for the organization of domain concepts. Properties are characteristics that describe an ontology class, such as definition, synonyms, relationships between classes, roles and links to external classification schemes (such as concepts in SKOS, inverse relation, attributes, values and comments). Instances are specific objects (individuals) of a concept. And axioms are restrictions on the concepts (classes and properties) involved in the ontology for multimedia annotation in order to avoid ambiguity in the semantics of the terms, thus guaranteeing that the formal definitions support the interpretation by the machine through logical inferences.

The ontology content analysis process consisted of a compatibility analysis (or semantic alignment) between the

Criteria	Description	Possible values	Weights	
Resource Reuse Effort				
Economic cost	if the ontological resource has any type of license, then the cost of acquisition and/or exploitation should be taken into account.	{unknown, low, medium, high}	(-)	9
Time required for accessing the ontological resource	if the ontological resource is accessible in slow servers or servers with bad connectivity, the time used for accessing should be taken into account.	{unknown, low, medium, high}	(-)	7
Resource Understandability Effort				
Documentation Quality	If the ontological resource is well documented.	{unknown, low, medium, high}	(+)	8
Availability of external knowledge	If the ontological resource have references to documentation sources and domain experts easily available.	{unknown, low, medium, high}	(+)	7
Clear Codification	If the ontological code is clear enough	{unknown, low, medium, high}	(+)	8
Annotations identified in the compatibilized terminology	Related to the existence and quality of annotations made in the elements of the compatibilized terminology of the candidate ontology, promoting relevant information about them.	{unknown, low, medium, high}	(+)	5
Resource Integration Effort				
Number of functional requirements covered	Related to the terminological coverage of the candidate ontology against the requirements determined in the research.	natural number	(+)	10
Suitability for knowledge extraction	Related to the structural similarities between the ontological resource to be reused and the ontology being developed, which includes the adaptation of definitions and axioms to satisfy the existing restrictions of the reasoner and the creation of new axioms and/or relations needed to integrate the ontological resource to be reused in the ontology being developed.	{unknown, low, medium, high}	(+)	9
Suitability for naming convention	Similarity between the ontological resource naming conventions and the naming conventions used in the ontology being developed.	{unknown, low, medium, high}	(+)	5
Adaptation to implementation language	Similarity between the ontological resource implementation language and the implementation language to be used in the ontology being developed.	{unknown, low, medium, high}	(+)	7
Resource Reliability				
Test Availability	Whether there are tests available for the ontological resource.	{unknown, low, medium, high}	(+)	8
Test Evaluation	Whether the ontological resource has been properly evaluated.	{unknown, low, medium, high}	(+)	8
Development Team Reputation	Whether the development team of the ontological resource is reliable.	{unknown, low, medium, high}	(+)	8
Reliability on goals of the project	Check if the ontological resource is supported by a contrasted theory in the case of common or general ontologies.	{unknown, low, medium, high}	(+)	3
Practical support	Whether there are well known projects or ontologies that are reusing the ontological resource.	{unknown, low, medium, high}	(+)	7
Use of available knowledge resources	Related to ontological resources (e.g., foundation ontologies, etc.) and non-ontological (e.g., metadata standards) used in the candidate ontology.	{unknown, low, medium, high}	(+)	8
Axioms identified in the compatibilized terminology	Related to the existence of axioms in the elements of the ontology, thus guaranteeing restrictions on their interpretations.	{unknown, low, medium, high}	(+)	6

Table 1. Criteria for the evaluation of the analyzed ontologies.

ontology vocabularies and the functional requirements proposed here. The analysis of compatibility took place especially in the elements of the ontological statements, in two aspects and in sequence: i) linguistic level; and, ii) level of definition of the concept. At the linguistic level, the interpretation of the chosen term is subjective, not being sufficient to ensure a correspondence to a given concept. Thus, as a second step, a conceptual analysis was performed, reflecting the intentional meaning of the element (term) against the intended context. For the latter, the annotation properties of the concepts (for example, comments and definitions) were checked and, when available, analyzed to obtain relevant information about their nature. The alignment considered semantic occurrences in the process of compatibilization of vocabulary, which can be characterized as: i) equivalence; ii) more specific; iii) more generic; and, iv) related. In (i), the semantics of two elements is equivalent in most possible contexts; in (ii), the semantics involved in the ontological element covers only a subset of possibilities expressed by the assimilated element; in (iii), the semantics involved in the ontological element is more generic than the properties involved in the assimilated element; and, in (iv), the two elements are related, but this relation has no definite semantics. Such an approach has been considered in ontology construction projects (Soergel 2017) that employ methods and techniques from the information sciences in the analysis of concepts and their relations. The methodological contribution and the consistent theoretical bases of the knowledge organization found in the information sciences can contribute with methods and techniques in the elaboration of categories, classifications, definitions and relations between concepts (Gomes 2017). Dahlberg (1978) contributes with the concept theory by proposing to analyze concepts in a universe of items for the realization of definitions, beginning with the observation of the referent, following a survey of its characteristics, finally arriving at the denomination through the term. In the organization of terms involved in a domain, Ranganathan's theory of the faceted classification (Ranganathan 1967) proposes to divide a subject by its multiple aspects or facets, that is, in groups of classes united by the same principle of division. The manifested categories in the facets serve as an instrument to facilitate the understanding of the nature of concepts and relationships, thus facilitating the activity of defining terms.

Finally, at the end of the analysis of each ontology, the data collected both in the documentary analysis and in the matrices resulting from the analysis of ontological content were carried out in order to obtain the evaluations and consequently the scores destined to the ranking of the ontologies involved. To this end, Table 3 was proposed to present the resulting assessments and scores. The method proposed by the NeOn guide to obtain the score for each evaluated ontology is described in the following steps:

- Transform the different values (quantitative and qualitative) as follows:
  - ValueT = 0 to Value = unknown (U)
  - ValueT = 1 to Value = low (L)
  - ValueT = 2 to Value = medium (M)
  - ValueT = 3 to Value = high (H)

Where "ValueT" is the quantitative value and "Value" is the qualitative value indicated by the ontologist during the content analysis of the ontology.

1. Transform the numeric value provided by criterion "number of functional requirements covered" using the following formula:

   Number of Functional Requirements Covered: ValueT = (Value/TotalRequirements) x HighestQuantitatveValue

   Where "ValueT" is the transformed value; "Value" is the number calculated for the criterion from the ontology content analysis; "TotalRequirements" is the total number of functional requirements determined in the survey (120 in total); and, "HighestQuantitatveValue" is the upper limit of quantitative values, which in this case would be value three according to the scale [0,3].
2. Calculate the score of the candidate multimedia ontologies as follows:

   The weighted criterion with (+) and the weighted criterion with (-) are treated independently. Thus, the following formula is proposed to obtain the weighted average for each type of criteria:

   Score i(+) = ∑ j (+) Value Ti, j x Weightj/∑j Weightj
   Score i(-) = ∑ j (-) Value Ti, j x Weightj/∑j Weightj

   Where:
   - "i" is a particular candidate ontology.
   - "j" is a particular criterion included in Table 1; j(+) means positive weight criterion, and j(-) negative weight criterion.
   - Score $_{i(+)}$ is the score for candidate ontology "i" for the weighted set of criteria with (+).
   - Score $_{i(-)}$ is the score for candidate ontology "i" for the weighted set of criteria with (-).
   - Value $_{Ti,j}$ is the transformed value for criterion "j" in ontology "i."
   - Weight$_j$ is the numerical weight associated with criterion "j."
3. Calculate the final score for each candidate multimedia ontology with the following formula:

   Score$_i$ = Score$_{i(+)}$ - Score$_{i(-)}$

After applying the final score for each candidate for reuse, it was possible to obtain the ranking and assess the ones with the highest score.

3.0 Results of comparative analysis of ontologies for multimedia annotation

From the comparative analysis performed on the seventeen criteria, it was possible to delineate relevant considerations on the four dimensions: reuse effort, understandability effort, integration effort, and reliability (Section 3.1); about covering functional requirements involving the three categories of metadata types: content independent, content dependent and content descriptive, as used in the survey (Section 3.2); and, about the ranking involving the nine multimedia annotation ontologies analyzed (Section 3.3). The results are presented in subsequent sections. It is worth noting that the method for obtaining the scores, as shown previously, was given by a weighted average involving determined weights and values measured for the criteria. For the latter, the scale of values was determined from zero to three as explained in the previous section. Finally, Table 2 presents a summary of the comparative analysis involving the ontology code inspection, and Table 3 presents the stratification of the evaluation of the seventeen corresponding criteria in each dimension against the nine ontologies evaluated.

3.1 Comparative overview of reuse effort dimension.

This section comparatively describes the reuse effort dimension for the nine analyzed ontologies, considering the value scales proposed in the research. Figure 1 presents a comparative view involving the four dimensions.

The dimension "resource reuse effort" remained stable for most ontologies (as shown in Figure 1) and, therefore, without considerable influence on their final score. The economic cost aspect was generally considered low due to the fact that the access to the nine ontologies was free through repositories indicated in the literature or links pointed by semantic web search engines. The time required ranged from low to medium. The ontologies evaluated with low access and opening time in Protégé were promptly analyzed. Boemie project ontologies, MPEG-7 Hunter and MPEG-7 Rhizomik were evaluated with average value due to some drawbacks in the access to their knowledge bases.

The "resource understandability effort," according to Figure 1, was the dimension that presented the lowest scores for the analyzed ontologies. Polysema MPEG-7, MPEG-7 Rhizomik, MPEG-7 Hunter and M3 Multimedia contributed to this, usually due to lack of documentary sources and/or lack of annotations. This was a disadvantage to them in the time-consuming aspect in order to understand their

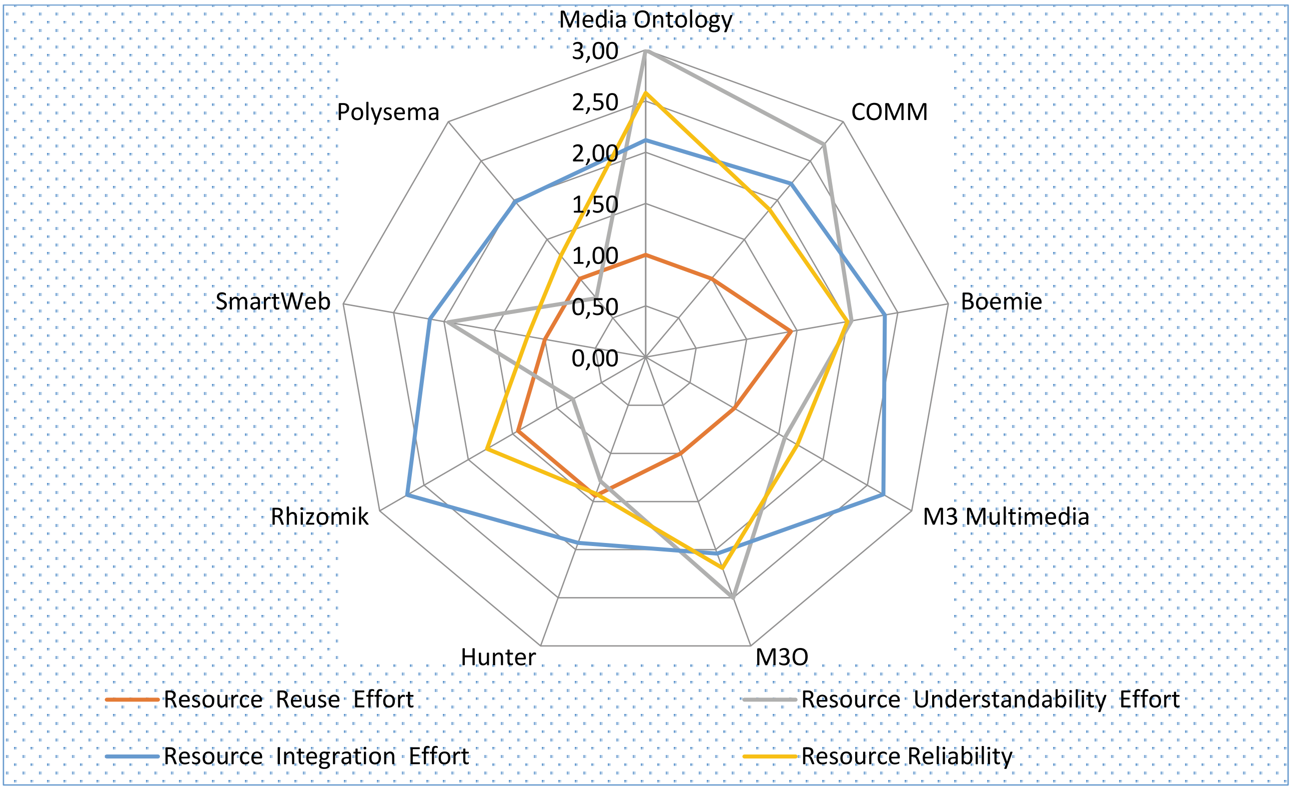

Figure 1. Comparative view of the reuse effort dimensions.

purposes, scopes and conceptualizations aiming at consistent alignments. On the other hand, Media Ontology stood out with a high score on all criteria (quality of documentation, availability of external knowledge, clarity in code and annotations in compatible terminology). It is believed that as a proposal from the W3C Media Annotation Working Group, which is specialized in semantic web media annotation issues, the team involved sought to make efforts to produce and make available documents concerning the ontology. The same occurred for the clarification of the ontology code, including favorable taxonomic organization with delimited concepts and adequate conceptual statements for most of its ontological elements, thus facilitating semantic interpretation by the ontologist involved in the analysis. Due to the quality of the proposal, proven in the results presented here, relevant information about Media Ontology is also found in other projects that have aligned with its structure, such as M3 Multimedia and M3O.

The "resource integration effort," according to Figure 1, was the most positive dimension compared to the other two with positive influence on the ranking and also the one that remained geometrically more stable. This reinforces that the method applied in the selection of ontologies for multimedia annotation to compose the research corpus was successful for a dimension that contemplates an important aspect related to the coverage of functional requirements. In this case, some relevant observations about the existence of gaps can be addressed to the proposition of recommendations for multimedia metadata modeling, as explained as follows. Metadata for media classification and use, content customization, and audio characteristics, both high and low, are little explored in the context of the ontologies analyzed. Audio-specific MPEG-7 descriptors are covered by the MPEG-7 Rhizomik ontology only. Some, such as MDO Boemie and SmartWeb MPEG-7, model audio resource classes but without axioms and annotations. The analyzed ontologies have various multimedia modeling strategies. Some propagate semantic ambiguities present in the MPEG-7 standard seeking to follow the flexibility of their schemes; others seek to restrict pattern-related classes and properties through axioms, as with MCO Boemie. One should think of the most convenient strategy from the perspective of using these ontologies on the web where the interpretative possibilities of agents (human and computational) are diverse. And finally, semantic annotation ontologies are designed as a means for the machine to interpret metadata with well-defined semantics that are necessary to ensure that the annotator and annotation consumer share the same meaning before a multimedia resource.

The dimension "resource reliability dimension" can be considered a feature present in most of the analyzed ontologies, according to Figure 1, by the following findings: i) all have a reputable development team; ii) all are assisted by major entities on the world stage, such as W3C, European Commission, German Federal Ministry of Education and Research, reputable European universities and renowned research centers; and, iii) a large part of them (M3O, COMM, Boemie, M3 Multimedia, Rhizomik) provide rich axiomatizations in their conceptualizations, which are based, in most cases, on high level ontologies, multimedia design standards, and in the MPEG-7 standard. Foundational ontologies and multimedia design patterns are knowledge resources effectively used only by COMM and M3O in the semantic organization of their multimedia elements. M3 Multimedia also does so indirectly when reusing the entire COMM knowledge structure, but it does not make clear in its scarce documentation how it takes COMM's multimedia standards in its conceptualization. And SmartWeb MPEG-7, in spite of using foundational ontologies for organizing semantic entities and integrating with domain ontologies, does not have a consistent framework for semantically organizing multimedia features such as segmentation and annotation.

3.2 Functional requirements coverage by metadata type category

This section describes how each analyzed ontology covered the functional requirements involving the content independent, content dependent, and content descriptive metadata type categories listed in the search. Figure 2 shows for each ontology analyzed the coverage index (see Table 2) for each category in relation to the total functional requirements present, as described below.

The category "content-independent metadata" has presented a higher coverage rate than the other two categories. The category was explored by all the ontologies analyzed. The most prominent ontologies were Rhizomik (100%), Media Ontology and M3 Multimedia, both with 87.5% coverage. The similarities on the coverage for both ontologies were due to M3 reusing Media Ontology descriptors for this nature. COMM (59.4%), SmartWeb (46.9%) and Polysema (62.5%) maintained a balanced index for this metadata category.

The category "content-dependent metadata" was consistently lower in coverage than the other two in most of the analyzed ontologies (except Hunter and Boemie), as shown in Figure 2. Audio and visual metadata are not represented by Media Ontology, Polysema and M3O. For the latter, as a generic and extensible model, metadata of this nature can be represented in its framework from the annotation pattern and data value standards. The other two do not mention this intention in their scope. SmartWeb covered a small portion of visual metadata with an 11.4% index represented by object classes and properties. COMM (45.5%), MDO Boemie (50%), M3 Multimedia (50%) and MPEG-7 Hunter

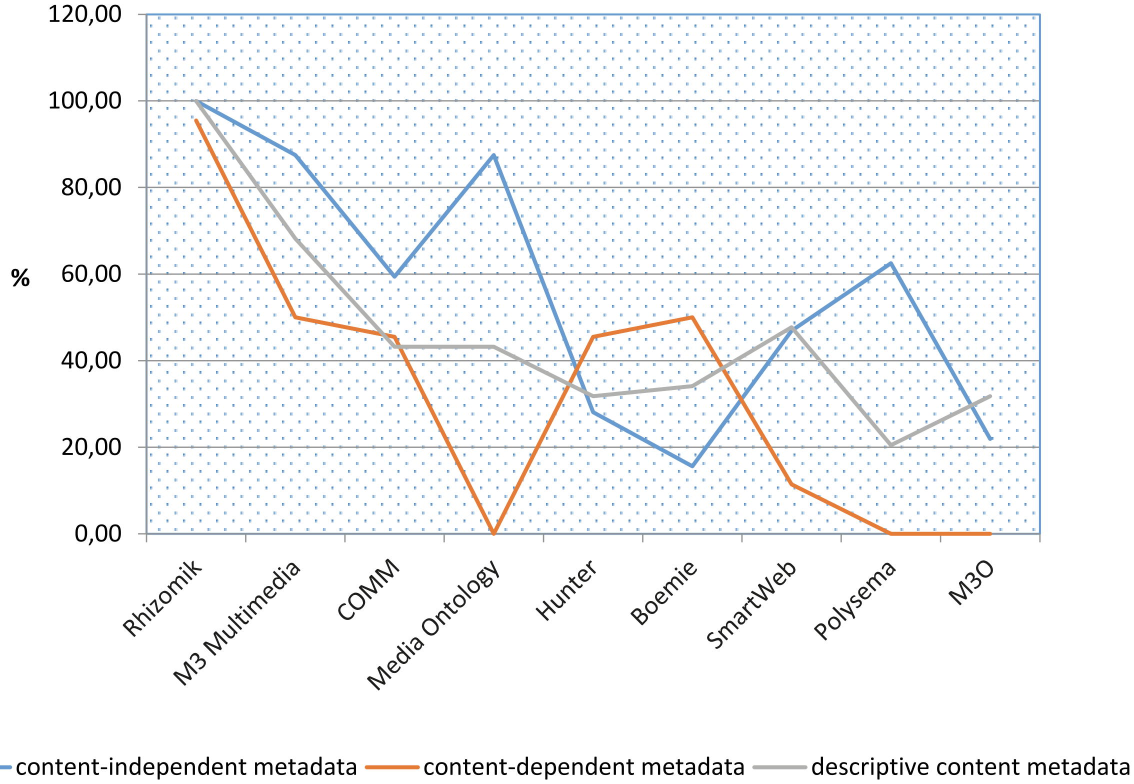

Figure 2. Coverage of ontologies per metadata type.

(45.5%) ontologies showed very close visual coverage rates for this category. The only ontology that stood out in the coverage of visual and audio metadata was MPEG-7 Rhizomik with a 95.5% index represented exclusively by classes. It should be noted that metadata for audio is not explored by the vast majority of analyzed ontologies. What is noticeable in some cases is the existence of taxonomies without axioms and generally without annotations to support future implementations of MPEG-7 descriptors for audio.

The category "descriptive content metadata" remained with an intermediate coverage index for most ontologies compared to the other two categories, as shown in Figure 2. Coverage was full or partial for all analyzed ontologies as follows: 100% by the MPEG-7 Rhizomik ontology; 68.2% by M3 Multimedia; 47.7% for SmartWeb MPEG-7; 43.2% for both COMM and Media Ontology ontologies; 34.1% for MCO Boemie; 31.8% for both MPEG-7 Hunter and M3O ontologies; and 20.5% for Polysema MPEG-7.

Finally, in terms of overall coverage, that is, taking all three categories of metadata previously compared, MPEG-7 Rhizomik stands out as the first (98.3%) in the coverage ranking, given that its purpose is to make MPEG-7 metadata available on the web while preserving the flexibility of the specifications of this standard. M3O came last (17.5%) in the ranking, because its purpose is not to focus on any specific metadata standard, like most ontologies analyzed, but on a generic multimedia modeling proposal capable of encompassing elements of metadata and ontological models derived from W3C semantic patterns. Figure 3 presents the consolidated coverage indices (see Table 2) corresponding to each ontology analyzed.

3.3 Overall ranking of ontologies for multimedia annotation regarding reuse

Figure 4 presents the overall ranking of the ontologies for multimedia annotation regarding reuse, and Table 3 the final scores. They were obtained by weighted average calculation involving the criteria with positive and negative influence on the ranking.

From this ranking and the findings from the comparative analysis, it would be possible to select and justify ontological resources appropriate to the reuse of knowledge resources aimed at the semantic organization of metadata for multimedia description. Some notes about the best placed ontologies in the ranking are detailed in the following paragraphs.

The Media Ontology can provide knowledge resources regarding content independent metadata given that it has a

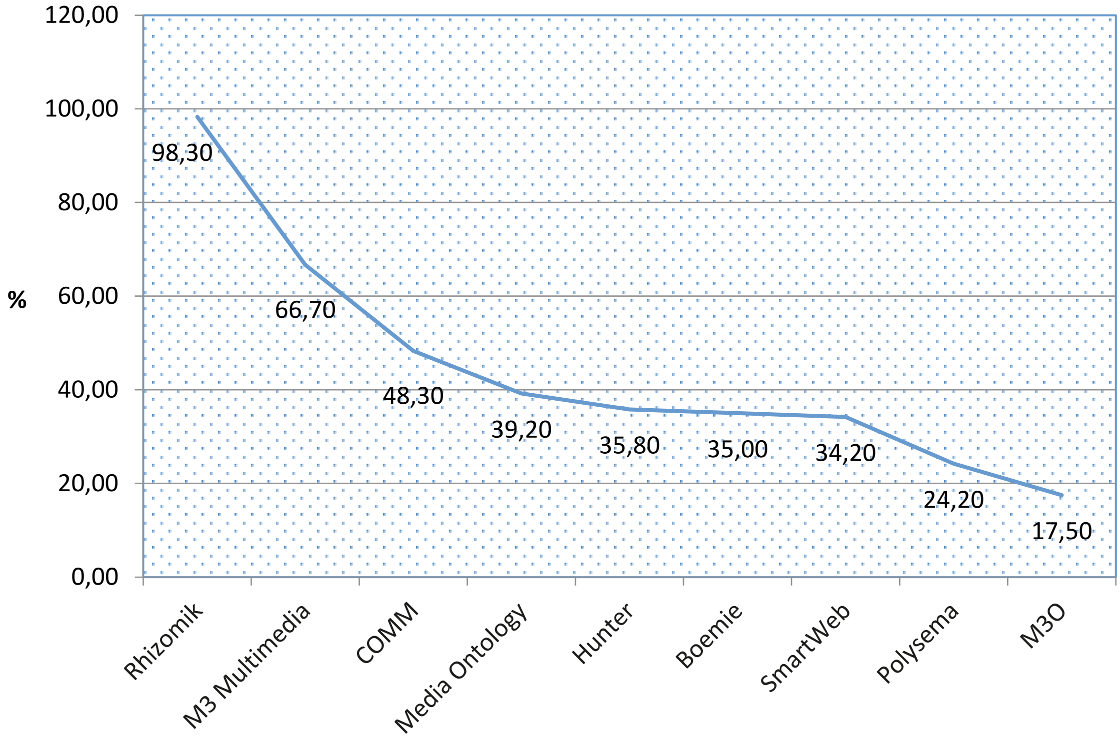

Figure 3. Consolidated coverage index for the ontologies.

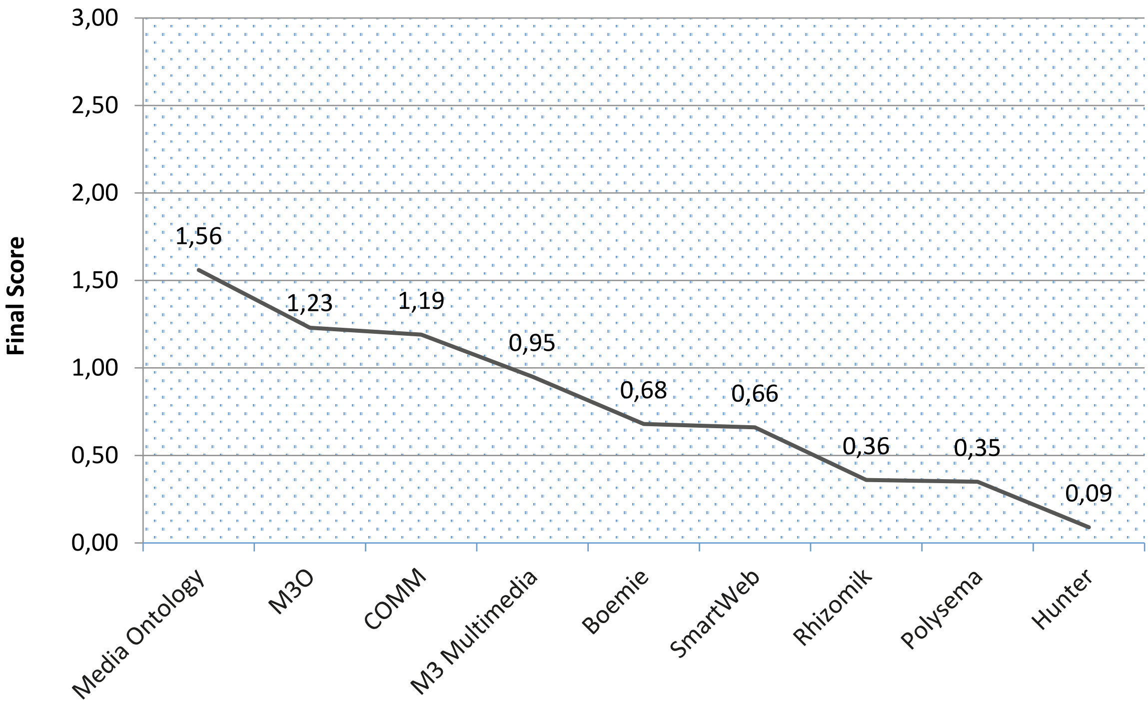

Figure 4. Overall ranking of the ontologies for multimedia annotation.

Aspects analyzed	Media Ontology		COMM		Boemie		M3 Multimedia		M3O		MPEG-7 Hunter		MPEG-7 Rhizomik		SmartWeb MPEG-7		Polysema MPEG-7	
Implementation language	OWL DL		OWL DL		OWL DL		OWL DL		OWL		OWL Full		OWL Full		RDFS		OWL	
Clear Codification	Clear nomenclatures for the concepts.		Complex taxonomic structure of abstract concepts derived from DOLCE ontology and extended multimedia patterns.		Clear nomenclatures for the concepts.		Clear nomenclatures for the concepts.		Entities organized by ontology content design patterns.		Definitions of classes and properties without significant comments.		Extensive taxonomy and no comment on its structure.		Extensive taxonomy, but with comments on its structure.		Simple taxonomy, but with no comment on its structure.	
Suitability for knowledge extraction	Specific subclasses for media characteristics.		Modularization for multimedia standards.		Modularization for media segments and media descriptors.		Modularization for multimedia, multi-domain and multilingual perspective.		Modularization for multimedia and provenance standards.		Specific subclasses for media characteristics.		MPEG-7 terminology.		Prefixes of knowledge resources used.		Specific taxonomy for multimedia description schemes.	
Suitability for naming convention	W3C metadata standards.		MPEG-7 metadata standard.		MPEG-7 metadata standard.		W3C metadata standards; MPEG-7.		Terminology adopted by the project team.		MPEG-7 metadata standard.		MPEG-7 metadata standard.		MPEG-7 metadata standard.		MPEG-7 metadata standard.	
Functional requirements covered – Categories of metadata types – Content-independent(32)	28	87.5%	19	59.4%	5	15.6%	28	87.5%	7	21.9%	9	28.1%	32	100%	15	46.9%	20	62.5%
Functional requirements covered – Categories of metadata types – Content-dependent (44)	0	0%	20	45.5%	22	50.0%	22	50.0%	0	0%	20	45.5%	42	95.5%	5	11.4%	0	0%
Functional requirements covered – Categories of metadata types – Descriptive content(44)	19	43.2%	19	43.2%	15	34.1%	30	68.2%	14	31.8%	14	31.8%	44	100%	21	47.7%	9	20.5%
Functional requirements covered – Coverage (120)	**47**	39.2%	**58**	48.3%	**42**	35.0%	**80**	66.7%	**21**	17.5%	**43**	35.8%	**118**	98.3%	**41**	34.2%	**29**	24.2%
Characteristics semantics – Axioms	20	42.6%	33	56.9%	35	83.3%	50	62.5%	17	81.0%	0	0%	103	87.3%	0	0%	15	51.7%
Characteristics semantics – Annotations	46	97.9%	53	91.4%	19	45.2%	41	51.3%	17	81.0%	41	95.3%	0	0%	41	100%	28	96.6%

Table 2. Overall content analysis of multimedia ontologies.

Criteria	Weights		Possible values																	
			Media Ontology		COMM		Boemie		M3 Multimedia		M3O		MPEG-7 Hunter		MPEG-7 Rhizomik		SmartWeb MPEG-7		Polysema MPEG-7	
Economic cost	(-)	9	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1
Time required	(-)	7	L	1	L	1	M	2	L	1	L	1	M	2	M	2	L	1	L	1
			1,00		**1,00**		**1,44**		**1,00**		**1,00**		**1,44**		**1,44**		**1,00**		**1,00**	
Resource Understandability Effort																				
Documentation Quality	(+)	8	H	3	H	3	H	3	L	1	H	3	L	1	L	1	M	2	L	1
Availability of external knowledge	(+)	7	H	3	H	3	L	1	L	1	L	1	L	1	L	1	U	0	U	0
Clear Codification	(+)	8	H	3	M	2	M	2	H	3	H	3	M	2	L	1	H	3	L	1
Annotations in the compatibilized terminology	(+)	5	H	3	H	3	M	2	L	1	H	3	L	1	U	0	H	3	L	1
			3,00		**2,71**		**2,04**		**1,57**		**2,50**		**1,29**		**0,82**		**1,96**		**0,75**	
Resource Integration Effort																				
Number of functional requirements covered	(+)	10	**47**	1.18	**58**	1.45	**42**	1.05	**80**	2.00	**21**	0.53	**43**	1.08	**118**	2.95	**41**	1.03	**29**	0.73
Suitability for knowledge extraction	(+)	9	M	2	M	2	H	3	H	3	H	3	M	2	M	2	H	3	M	2
Suitability for naming convention	(+)	5	H	3	H	3	H	3	H	3	M	2	M	2	H	3	H	3	H	3
Adaptation to implementation language	(+)	7	H	3	H	3	H	3	H	3	H	3	H	3	H	3	M	2	H	3
			2,12		**2,21**		**2,37**		**2,68**		**2,04**		**1,93**		**2,69**		**2,14**		**1,98**	
Resource Reliability																				
Test Availability	(+)	8	H	3	U	0	U	0	U	0	M	2	U	0	U	0	U	0	U	0
Test Evaluation	(+)	8	H	3	U	0	U	0	U	0	L	1	U	0	U	0	U	0	U	0
Development Team Reputation	(+)	8	H	3	H	3	H	3	H	3	M	2	H	3	H	3	M	2	M	2
Reliability on goals of the project	(+)	3	H	3	H	3	H	3	H	3	H	3	M	2	M	2	H	3	H	3
Practical support	(+)	7	H	3	H	3	H	3	L	1	M	2	M	2	M	2	L	1	L	1
Use of available knowledge resources	(+)	8	M	2	H	3	H	3	H	3	H	3	H	3	H	3	H	3	H	3
Axioms in the compatibilized terminology	(+)	6	L	1	M	2	H	3	H	3	H	3	U	0	H	3	U	0	L	1
			2,58		**1,88**		**2,00**		**1,71**		**2,19**		**1,42**		**1,79**		**1,17**		**1,29**	
	Score (+)		2.56		2.19		2.12		1.95		2.23		1.53		1.80		1.66		1.35	
	Score (-)		1.00		1.00		1.44		1.00		1.00		1.44		1.44		1.00		1.00	
	Score (=)		**1.56**		**1.19**		**0.68**		**0.95**		**1.23**		**0.09**		**0.36**		**0.66**		**0.35**	

Table 3. Results of the criteria evaluated in multimedia ontologies.

coverage ratio of 87.5% for this category compared to 59.4% for COMM. In addition to the coverage factor, Media Ontology stands out compared to the nine ontologies analyzed as shown in Figure 4. This evidence is combined with the fact that this ontology comes from the W3C Media Annotation Working Group. Media Ontology was built using standards of ontology engineering methodologies, and its purpose was to define a set of properties of central annotation for describing multimedia content, along with a set of mappings between the major metadata formats in use today, highlighting Dublin Core and MPEG-7.

M3O ontology can provide knowledge resources grounded in upper ontology as well as multimedia design standards, and address semantic differences between content and media formats. M3O's conceptualization architecture is based on the upper DOLCE + DnS Ultralight (DUL) ontology and in three design patterns referenced by it, namely Description and Situation (DnS), Information and Realization Pattern and Data Value Pattern. The M3O multimedia standards are extended from AnnotationPattern, DecompositionPattern and CollectionPattern. Their design diagrams are easily recognizable by the simplicity of their few class and relationship schemes, which makes it possible to understand the modeling reasoning employed in the conceptualizations. In addition, the three multimedia standards act on the semantics specified in the Information and Realization Pattern, which represents the distinction between information objects and information realizations—a feature similar to the *FRBR* model proposal in the use of semantic abstractions related to the expression and manifestation of a work. The separation between information objects and information realization becomes relevant in order to provide a clear distinction between semantics (message content) and data (media format). Thus, annotations, decompositions, and collections may involve information objects and information realizations.

Metadata focused on content semantics are often linked to instances of domain ontologies whose semantic labels are organized into the taxonomic structure of a grounding ontology. Because M3O integrates with the DUL grounding ontology, it can fulfill the role of organizing semantic labels from domain-specific ontologies into entities such as event, object, time, place, etc., and address their relationships. In addition, M3O with its multimedia design standards also fulfills the role of addressing three situations involving the content descriptive metadata category, namely: i) DecompositionPattern, which deals with decomposed media and resulting segments; ii) AnnotationPattern, which deals with the metadata involved in segment annotation; and, iii) CollectionPattern, which deals with metadata related to the organization of multimedia content.

Knowledge resources associated with content-dependent metadata can be selected from COMM and M3 Multimedia ontologies, as Media Ontology and M3O ontologies do not cover such a category. The purpose of COMM ontology is to provide a sound conceptualization for multimedia annotation that broadly covers a specific domain that deals with multimedia content. M3 aims at modeling multimedia information for any type of resource across multiple domains and in multi-language context. COMM and M3 had very close visual coverage indices. Knowledge resources related to audio metadata can be selected from M3 Multimedia, which owes its quality to the reuse of both visual and audio metadata from the VDO Boemie ontology. Although audio descriptors have not been represented in their specificity (in accordance with ISO MPEG-7), the taxonomy in M3 Multimedia is modeled to include such descriptors.

Finally, despite its unfavorable ranking position, MPEG-7 Rhizomik ontology is recommended as a reference source for ontologists involved in semantic modeling of multimedia metadata. As Rhizomik ontology came from a proposal for full MPEG-7 translation, its evaluation was positive in the effort for integration dimension (2.69 on a scale of zero to three). Thus, descriptions with axioms belonging to ontology may be useful in proposing a reference model for the organization of metadata of this nature.

4.0 Conclusions and future work

The main contribution in this article is the result of the comparative analysis involving multimedia ontologies. We have offered a ranking of ontologies, achieved through a weighted scoring method. This allows researchers to advance with new models and conceptual model of multimedia reference based on the reuse of previously classified ontologies with an adequate scientific basis. The results aimed at contributing to the field of information science, especially for the area of knowledge organization and representation. We have proposed an analytical and careful study of knowledge organization systems, including metadata standards, vocabularies and ontologies focused in the organization of metadata for describing multimedia resources on the web. We took in account the overall concept for metadata, namely, "data about data" (Gilliland-Swetland 2016), but tried to specify the uses, syntaxes, and appropriations that are different in degree, complexity and cost (Van Ossenbruggen et al. 2004). Thus, the central concern can be posed as follows: how to effectively index, catalog and retrieve multimedia content for the numerous existing metadata typologies to varying needs and circumstances. The results of this research can contribute to the perspective of possible solutions for the treatment of the various types of metadata for describing collections with multimedia content.

A commonly observed problem in institutions that make use of multimedia document (photographs, letters, drawings, periodicals, audio and video interviews, radio and video recordings, among others) collections—mainly digital, and most of the time for the use on the web—is in the comprehensive treatment of heterogeneous databases and in the absence of standardization in the description formats. The items are usually described using idiosyncratic patterns, highlighting different characteristics and using different terminologies. This practice culminates in problematic situations for information retrieval systems, such as: i) search made by isolated and decontextualized words, which hinders greater visibility of the collection from the perspective of users and, consequently, search engines; ii) lack of context in the media items described (how are photos and videos related to text?); iii) conceptual ambiguity (which concept is precisely speaking of?); and, iv) little relevance to the recovered resource.

Comparison of various multimedia annotation ontology proposals against ISO metadata standards such as MPEG-7 and Dublin Core has highlighted relevant features that can and should be described for better retrieval of multimedia resources, especially in the context of the web. The need for semantic integration and global availability of multimedia resources in the web is a common purpose among the proposed ontologies assessed. The ranking of ontologies, a product of comparative analysis in four dimensions concerning reuse, showed the most prominent ontologies for the domain under study, namely, in this order: Media Ontology, M3O, COMM and M3 Multimedia. It is possible, then, to select the knowledge resources from their structures from the confrontation with determined functional requirements that would allow the proposition of a conceptual model of multimedia reference. The sense of "reference" is what characterizes the model as an artifact underlying research efforts focused on models and technologies for multimedia metadata processing involving semantic web, digital library, knowledge representation, and multimedia communities.

The conceptual model of multimedia reference could be proposed as a broadly encompassing solution for multimedia representation as the result of a methodical, well-grounded and careful evaluation performed on ontologies for multimedia description. Benchmarking has provided the necessary conditions for the selection and reuse of appropriate knowledge resources to represent a comprehensive taxonomic framework capable of supporting generic concepts arising from multimedia design patterns, along with metadata type classes (independent, dependent and content descriptive) that foresee a clear separation of interests in relation to the media, namely: content semantics, knowledge related to the management of information resources, structural aspects of content and characteristics of documentary reality of multimedia type.

Problems associated with aspects of semantic and syntactic interoperability required by multimedia web applications can be alleviated by the formal nature of the DUL foundation ontology and its M3O ontology content design patterns. Such frameworks ensure that the intended meaning of the semantics captured in the reference model can be shared between different applications within the scope of the semantic web and convey a syntax agreed upon by this community through the use of the OWL language.

The conceptual model of multimedia reference could also be used in information systems aimed at cultural heritage institutions, such as archives, libraries, museums, documentation centers and memory projects, whose users consume, interpret, manipulate and generate multimedia content in the collections held in digital repositories. Another possibility of use would be in news portals of the most varied nature that need efficient methods to organize multimedia content and transmit it efficiently to users.

Finally, the conceptual model of multimedia reference could still be inserted in the context of digital humanities (Liu 2012; Koltay 2016), an emerging field of research capable of bringing together the areas of information and communication technology and the humanities, seeking to make more access and retrieval of information through the application of technologies. Another context in which the conceptual model of multimedia reference could be targeted would be the LOD cloud, as a way to aid the publishing standardized open data using semantic web technologies, allowing global data queries and links between data from different sources. For example, queries could be made using specific data sources, as well as other external sources such as the DBpedia knowledge base. In this regard, new knowledge can be generated by crossing data, allowing various types of custom queries.

Notes

1. http://mpeg.chiariglione.org/standards/mpeg-7/visual
2. http://mpeg.chiariglione.org/standards/mpeg-7/audio
3. https://mpeg.chiariglione.org/standards/mpeg-7
4. http://dublincore.org/documents/dces/
5. http://watson.kmi.open.ac.uk/WatsonWUI
6. http://swoogle.umbc.edu/
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