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Knowledge Organization Systems for Semantic Digital Libraries

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Abstract. As the traditional knowledge organization systems (KOS) like classification, thesauri are paving way for ontologies, trans-technological data models and semantic networks of data exchange provide impetus for developing semantic digital libraries. This paper attempts to find the KOS in the early digital libraries, and how they can be integrated with the digital library architectures using emergent semantic technologies and data. Metadata remains as a core area at the heart of the Semantic Web and realizing semantics on machines is the challenging task of Web services development. Knowledge representation and organization systems explore nature of metadata and their semantic relationships. This new-breed of social and semantic technologies and their potentialities, approaches for organizing the knowledge on the Web and their enjoining with digital libraries in the light of evolving Semantic Web is highlighted.

Keywords: Knowledge organization systems, digital libraries, Semantic Web, semantic digital library, metadata semantics

1. Introduction

Metadata is data that describes the content, format or attributes of a data record or information resource and can be used to describe highly structured resources or unstructured information such as text documents (Haynes, 2004). Metadata semantics envision a state where the data about the data is transforming to make metadata out of data (Nilsson, 2010). After the Internet revolution, the World Wide Web has set the stage for co-creative, entrepreneurial and an enterprising lynchpin of *'New Web of Things'* as Greg (2012) puts it. With web being unfashionably cluttered, time is ripe to organize the *Web of Data* using the metadata semantics as varied as social to research data on the Web. As keyword-based search engines have high recall and low precision, low or no recall, insensitive to vocabulary, the need for machine processable data as such necessitates the Semantic Web (Antoniou et al., 2005). Initially artificial intelligence techniques were applied for knowledge re-engineering to achieve the semantics, but maintaining the knowledge bases is not an easy task either. Even more the manifestation of digital libraries (DLs) as one of the important knowledge based system has thrown up potential challenges for knowledge acquisition as well as integrating with intelligent applications (d'Aquin et al., 2008). Moreover, Web need knowledge organization tools to keep it less noisy and more precise in the light of semantic heterogeneity of information resources and semantic complexity of knowledge representation (Shapiro, 2010). The world is embarking on a journey from the *Internet of Things* to an ubiquitous, '*New Web of Things*' where the big data, open content, ontologies interact with the software agents to bring forth the real-time integrated just-in results expressed through consistent semantic data by correlating metadata with semantics and enhanced semantic infrastructure. Web is turning out to make a universal, neutral and open platform to present things and offer services in unified ways. To make that happen, software agents, data analytics and metadata semantics are to be integrated to launch the Web services in a semantics-enriched ecosystem through formalisms and logical reasoning. As increasingly metadata is linked to other works like reuse, user-generated social metadata, linked data and semantic applications, future of metadata hinging upon an open system is a boost for innovative ways of resource description and semantics-enriched environments (Smith-Yoshimura, 2011). Open metadata further provides opportunities for resource discovery by enabling a rich machine-processable and disambiguous information retrieval. As an example Harvard University has announced releasing of 12 million catalogue records publicly available under a Creative Commons License in public domain (Schwartz, 2012). Digital libraries as a contentious player can be integrated with lightweight ontologies, linked data and faceted infrastructure where knowledge organization and information retrieval are reciprocative (Stock, Peters & Weller, 2010).

The description, use and retrieval of diverse information sources in a distributed environment are biggest challenges of knowledge organization in a networked world. Since the time Internet and data semantics took off, investigations are on to combine these two phenomenal developments with semantic technologies that can facilitate semantic information retrieval of meaningful and contextualized results. Although many challenges lie ahead such as word sense disambiguity and content diversity for organizing knowledge on the Web, the digital information services rendered through digital libraries got off the ground opening up vistas which are pivotal for open access, global reach and accessibility beyond the limitations posed by business intermediaries, affordability and inaccessibility in strengthening social capital of a knowledge economy. Semantic digital libraries conceive this as a kind of knowledge structures to the *Web of services*, that allows computers to deal with its content in meaningful ways where meaning or semantics can be discernable, shared, and processed by automated tools and people (Taylor, 2004, p. 96). For the semantic digital libraries to function, computers must have access to structured collections of information, KOS, sets of inference rules to conduct automated reasoning, annotation and semantic extraction of metadata from digital libraries and social Web. As metadata is getting fine-grained for interoperability, cross-walking and granularity, their interaction with the semantic technologies are expected to yield a search ecosystem where meaning-based, contextualized and unambiguous information retrieval would expected to be a norm. For example Schema.org is one such attempt towards realization of Semantic Web by search engine organizations Google, Yahoo and Bing collaborating together for creating schema and developing standards using markup languages to find relevant web pages by deploying microdata and microformats.[1] Among the other upcoming challenges to achieve the Semantic Web goals as noted by Legg (2007, p. 413-415) are:

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[1] http://schema.org/

- **Inferential tractability** - the ability of the logical expressivity of the languages used to represent and to query languages
- **Logical consistency** - is the vision of machine reasoning on the Semantic Web comprising deductive inferences
- **Rapid changeability** - refers to the exponential rate of change across Web pages and over a period of time
- **Politico-technicality** - of evolving standards and schemata which could be embedded with the markup languages and the incentives for developing semantic metadata by applications and stakeholders.

2. Knowledge Organization Systems for Digital Libraries

Digital library can be defined as a quadruple consisting of a repository, a set of metadata catalogues, a set of services, and a society that allow a community of users to access and re-sue the digital objects. As the digital library universe evolves, its content, data modeling to support, identification, description, and discovery of digital objects are explored to lay the foundations of semantic digital library (Meghini, Spyratos & Yang, 2010). Digital libraries ideally represent the needs of heterogeneous information resources combining the development of complex systems issues such as interoperability among existing data providers, distributed retrieval, and long-term preservation as well as new issues viz., social network models, large-scale computing, micro information and embedded semantics (Candela, 2010).

Knowledge organization in its broader sense involves organizing the metadata of the information resources with their meaning, arrangement and display and if retrieved should produce exact, relevant and timely search results. For the growing digital content in libraries and *Web of data* offering data services comes as a natural extension of information services that libraries are striving for (Stuart, 2011). In one sense, this is what the semantic digital library resonates – finding the meaningful, contextualized and relevant results. Metadata being the cornerstone of the semantic web, enhancing DL architecture with semantic applications enable an integrating environment for semantic query, annotation and information retrieval, for which JeromeDL[2] stand as a pioneering example. As the metadata semantics evolves digital libraries should be able to infer data out of the DL structure and architecture instead of depending on static, linear hierarchies of information which tend to work on ad-hoc and task-specific frameworks of DL technologies (Gómez-Berbís, Colomo-Palacios & García-Crespo, 2008). Moreover, data repositories have grown in size, volume and of varying purposes from subject to learning object repositories (See the institutional repository categories at EPrints[3] and ROAR[4]), and there are widespread needs felt to integrate the resources on a single-platform for federated retrieval or combining the architecture with other silos of the information architecture of libraries for unified, search results across the integrated library management system seamlessly. Shiri & Molberg (2005), in their findings reported that 33 digital collections in Canada have employed some type of KOS in their search interfaces.

As semantic technologies influence the Web-based information services, it necessitates ascertaining how the semantic data can be fine-tuned for semantic-based web services to take off. As digital libraries increasingly project the library services to the wider user community through perpetual access, preservation and archiving, it is time to tap the semantic technologies. The first generation digital libraries post-1990s, have used traditional KOS to organize the collections, but, open contents and digital objects on the World Wide Web are mapped with metadata and their relationships are examined for the emerging Semantic Web, "a Web for machines, where not only is data distributed for human consumption, but also the data on the Web will be machine-processable (Fensel et al., 2007)." The early digital libraries like arXiv and RePec had used various kinds of KOS as shown in Table 1.

Name of Digital Library and URL	**Established Year**	**Subjects Coverage**	**KOS Used**

2 http://www.jeromedl.org/
3 http://www.eprints.org/exemplar.php#data
4 http://roar.eprints.org/view/type/

ArXiv - http:// arxiv.org/help/ general	1991	Mathematics, computer science, nonlinear sciences, Quantitative biology and Statistics.	Subject headings
NDLTD - http:// www.ndltd.org/	1991	Electronic theses and dissertations	Subject headings
SSRN - http:// ssrnblog.com/about/	1994	Social sciences	Journal of Economic Literature Codes Classification
RePec - http:// ideas.repec.org/	1997	Economics	Journal of Economic Literature Codes Classification
CogPrints - http:// www.iam.ecs.sot on.ac.uk/projects/ 49.html	1999	Psychology, neuroscience, and linguistics, computer science, philosophy, biology, medicine, anthropology.	Subject headings
E-LIS - http:// eprints.rclis.org/	2003	Library and information science	JITA Classification System for Library and Information Science

Table 1. KOS in the Beginnings of Digital Libraries

Moreover, the next-generation digital libraries are dependent on networked KOS, ontology models, metadata standards, and semantic query languages. Different attempts are made on how the data can be sliced and diced on the digital libraries to reuse, processable data by building layers of semantic resource discovery and semantic data applications on top of the existing digital library architecture. Some of the applications like Dwell for faceted browsing, DuraSpace using DSpace, Fedora Commons and DuraCloud for an enhanced digital library suite on a hosted cloud computing are examples of upcoming new semantic digital library infrastructures. There is a widespread criticism that as the Web evolved, it has created its own course of action, with less attention to knowledge organization models and epistemological approaches (Tredinnick, 2007). In order to overcome the inefficiencies of text based information retrieval, ontologies came into play with their advanced conceptual schema centered on machine-understandability. But this machine-understandability is reliable on how universal, explicit, and theory of meaning of metadata and standards to achieve the semantics are (Legg, 2007, p. 407). Knowledge representation and organization serve to find the aboutness and thought-content of digital objects. When the content of a digital object is represented as perceived (knowledge representation), described as standardized (metadata description) and exposed to semantic technologies (Triplification, OWL, Ontologization) the cycle of semantic data discovery ends (See Figure 1 generated using Sindice[5]). When digital objects are stored in a digital library and its architecture equipped with semantic layers should be able to perform this task which is knowledge organization (Meghini, Spyratos & Yang, 2010):

- provide representations of digital objects
- describe an object of interest according to standardized vocabulary
- discover objects of interest based on content or description

3. Need for Metadata Semantics

Metadata on the Web is set to be expanding from bibliographic, collection-level metadata to classificatory ontologies such as subject headings, and article-level content such as links, identifiers, linked data and references which would increase the value of the digital content by providing novel ways to discover and navigate through the plethora of electronic resources (Page, 2010). Linked data modeling enabled million of web pages into billions of triples based on the notion of open access to structured data and as the Web players are turning on the semantic-friendly features there are tens of billions of RDF triples and approximately half a billion marked up web pages (Tummarello et al., 2010). Growing with the diverse information resources, industry players developed their own metadata

[5] http://sindice.com/

standards and domain-specific applications such as Dublin Core, MODS and MARC family for general purposes; CDWA, CCO and VRA Core for cultural objects and visual resources; IEEE LOM, CanCore, SCORM and Dublin Core Education Application Profile (DC-ED) for educational resources; EAD for preservation metadata; MPEG-7, ID3v2 and PBCore for multimedia objects etc. (Zeng & Qin, 2008). The Web in its all cluttered entirety necessitates the metadata semantics, because there is lack of metadata harmonization[6] and semantic intelligence. Moreover, the semantic metamodels would bridge these gaps bringing the cutting-edge semantic layers and architectures together.

4. Semantic Digital Libraries

Since 1990s DLs have emerged as the potential scholarly communication channel in view of the challenges such as budget cutbacks and price models, which have widely affected the libraries worldwide. Evolving in the next decades, the DLs have grown into architecting data models and semantic architecture that combine the advantages of Semantic Web and information retrieval efficiencies what we achieved by for now. As the Semantic Web services are casting their deployability on DLs the data model frameworks and semantic layers are being built upon the digital collections in order to make them more discoverable, interoperable and semantics-enriched metadata on the Web (Mecgregor, 2008). Semantic digital libraries involves developing strategies for up-scaling architecture, semantic search engines and applying semantic techniques for automatic metadata generation and their evaluation in digital library collections (Kruk, Decker & Zieborak, 2005; Tönnies & Balke, 2009). Semantic digital libraries are integrated with social semantic data and services architecture that help to tap the potential of social semantics (Kruk et al., 2007). Few semantic digital library instances and applications explained show the Semantic Web features in Table 2. If the strengths of metadata semantics are combined into the architecture of the digital libraries the result of semantic digital library services will be a boost to capitalize on the Open Data[7] and open access movement even as the potentials of

[6] http://wiki.dublincore.org/index.php/Glossary/Metadata_Harmonization
[7] http://www.data.gov/

Linked Data are investigated (Berners-Lee et al., 2006). The scope of DLs have been expanding from a pure repository into variety of categories and functions such as data repository and web archives[8], hence organizing the content based on the semantic technologies is of paramount importance. Since the metadata of individual document to set of collections are open to ontologization, semanticizing, encoding and processable using knowledge organization tools and techniques is tenable to achieve the semantics in digital libraries. Figure 2 show the major thrust areas of research which strives to bring in the capabilities of metadata semantics and Semantic Web features together for Web services development. As the semantic technologies gain ground for deployability semantic digital libraries are already implemented. For example JeromeDL has been implemented in Gdansk University of Technology.[9] Semantic search engines incorporate search computing techniques that foresee the fundamentals of Web indexing, optimization to crowdsourcing. Semantic search encapsulates a concept-based, semantic matching and ontology-centric framework for providing extant search results for which Hakia, Kosmix and Kngine are the prototypes (Mankani, 2011).

5. KOS and Metadata Semantics

As traditionally known, organizing the knowledge has evolved from the epistemological and philosophical foundations of metaphysics domain. Organizing multifarious, advanced knowledge logically by certain attributes and relationships was necessitated as a vocabulary control aid for easier physical access and as controlled semantics on Web by post-Internet period. Since the Semantic Web was proposed by Berners-Lee, Hendler & Lassila (2001) there are many initiatives, applications and schemata drawn and implemented for far more visible results of semantics on Web. Borst, Fingerle & Neubert (2010) had argued that KOS for libraries is robust and outweigh "in contrast to many other database providers, possessing reliable metadata and context data (such as name or corporate body authority files, classifications and thesauri)." As the metadata semantics is expanding domains ranging from biomedical engineering to knowledge management,

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8 http://roar.eprints.org/view/type/

9 http://pbc.gda.pl/dlibra

applications are developed by different domain-specific requirements. SIMILE suite of application for digital libraries, Searchling for bilingual searching and MARCOnt integrating ontology for bibliographic formats

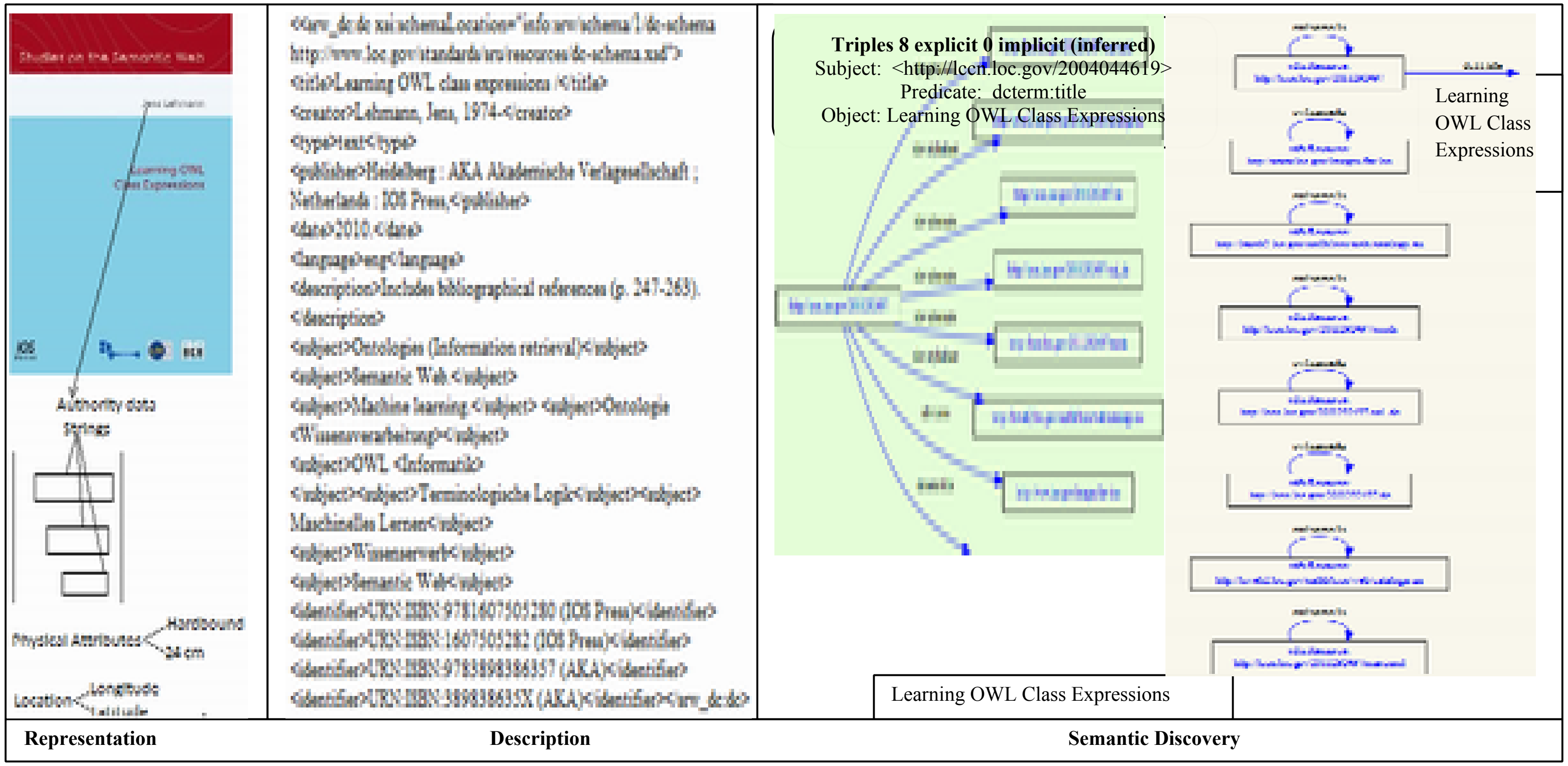

Figure 1. Knowledge Organization Systems and Metadata Semantics

Tool	Semantic Technology	Querying Capability	Semantic Web Features	URL
JeromeDL	Semantic digital library	RDF query (SPARQL)	Federated search, faceted browse, semantic query expansion, JeromeDL–specific core ontology, and description of content	http:// pbc.gda.pl/ dlibra
reflect.ws	Semantic annotator	URIs and free text search	Concepts highlighting, tagging, and augmented browsing of semantic annotation	http://reflect.ws/
Sig.ma	Semantic information mashup	RDF query (SPARQL)	Social semantics application combines the structured data and displays the aggregated content from local data source and remote services	http://sig.ma/
VIVO	Semantic data on researchers	RDF query (SPARQL)	Visualization of people data, research output of organizations, grants and networks of scientists using semantic web-compliant data	http:// vivo.ufl.edu/
SIMILE	Social semantic digital library	Free facet search	Community-driven taxonomies, social semantics, Cross-repository semantic interoperability for mapping diverse metadata in RDF	http:// simile.mit.edu/

Table 2. Semantic characteristics of DL and semantic web applications

are few examples of noteworthy. In order to achieve the semantics-based digital libraries the approaches are varied. Libraries are inevitably important to make the bibliographic data semantically viable for resource discovery using URIs for resource identity management, vocabularies for managing namespaces and authority files and query interfaces for semantic representation and annotation (Svensson, 2007).

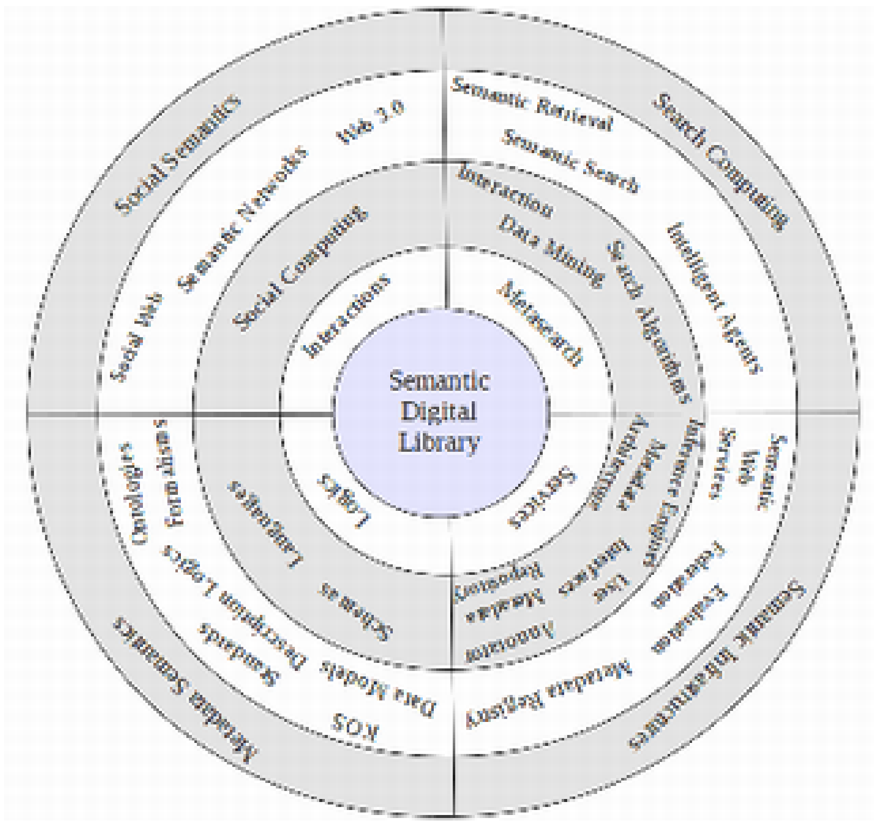

Figure 2. Facets of research in metadata semantics

Figure 3 portrays the metadata stack an emerging meta-modeling of metadata architecture aligning with the ideals of Semantic Web. Expressiveness of metadata relationships and attributes increase the extensibility of metadata using new schemata and standards as shown in figure 4. Extensibility of the metadata has to be examined as to how the object attributes and properties can be schematized to incorporate into the metadata standards.

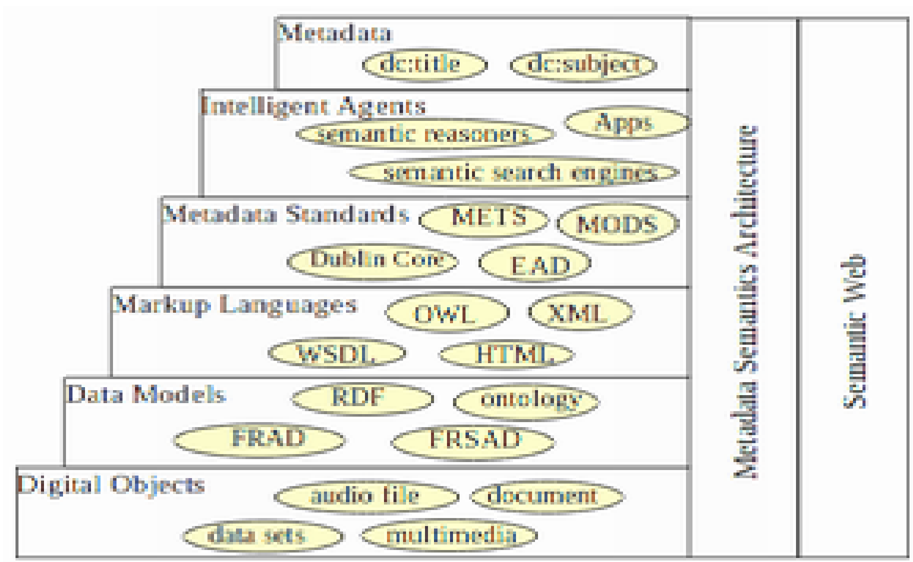

Figure 3. The Metadata Stack

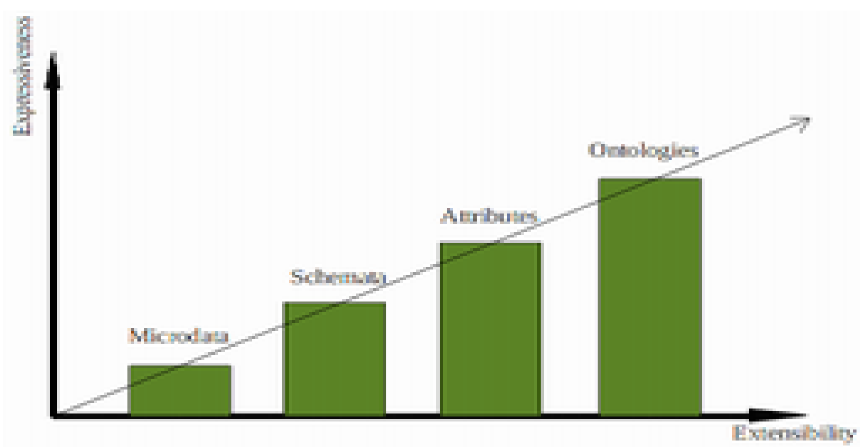

Figure 4. Extensibility of metadata

5.1 Emerging Approaches of KOS for DLs

The evolving semantic networks and techno-infrastructure today involves using metadata that ranges from biological to bibliographic data of various domains. Building the KOS onto the architectures of DLs can be possible if KOS standards (e.g., SKOS), KOS registries, and KOS structures are developed that they can be integrated with the services protocol and best practices of DLs (Hill et al., 2002). Understanding the structure and architecture of the metadata necessitates the modeling and representation of data such as namespaces (authority files), entities (objects), ontologies (concepts, classes and attributes), and geospaces (place names and geodata) and standards to normalize data for machines to process for semantic retrieval. Moreover, since data is explored with its meanings the data is to be enwrapped with the new technologies which bring out the semantics of data on the Web.

5.1.1 Information Extraction

Using semantic technologies is to extract the metadata for autorecognition of concepts and topics, and automatic extraction of information and meaning and categorization in a distributed environment from multiple sources (Madalli, 2010). Creating ontologies including propositional knowledge for machine processing is one way, but accuracy of machine-processed results always warrant human intervention (Soergel, 2009). Deploying semantic annotators and ontological creation and engineering tools extracting metadata from information sources is another option for computer-supported information extraction using algorithmic statistical methods. Ontological engineering techniques are employed for creating lightweight ontologies to facilitate document representation and retrieval techniques is another trend (Sánchez et al, 2012).

5.1.2 Controlled Semantics

Metadata interoperability and metadata harmonization lie at the heart of the semantics where the exchange of metadata is consistent with the interpretation of the creator of the data and consistent with the intentions of the creators of the metadata (Nilsson, 2010). Identifying metadata vocabularies for wider interoperability across domains, applications and their resuability can be imagined if two systems can exchange machine-processable semantics alongside the metadata and interpret semantics correctly. Moreover, as the SKOS vocabularies gain ground, the semantics and extensibility of the controlled semantics can be shared among the collaborative digital libraries by using open metadata registries.

5.1.3 Open Linked Data

Since governments, data-intensive scientific domains and libraries are opening up vistas for open data, increasingly the open data and content would amount to larger metadata repositories around the world to *'Web of Data'*. Web of discovery can happen if the enriched semantic metadata provide connections across the different sources of data such as indexed content and linking data sets which will lead to semantic discovery. In order to overcome the challenges of traditional controlled vocabularies such as maintenance cost, interoperability and usability to a contemporary machine-to-machine transacting, flexible, extensible and robust controlled semantics are needed in place. If the *Linked Data* expertise is leveraged for open data with newer data exchange models, metadata can be reused for developing applications. Ontologies could be integrated, versioned and controlled with the linked data which would motivate for furthering the research in metadata semantics using domain and upper ontologies. Moreover, new technology promises benefits which accommodate the data storage and retrieval needs in the foreseeable future and libraries will be embracing newer bibliographic framework initiatives[10] and data models while preserving the data exchange. Linked Data is a recommended practice for gathering scattered information pieces to a sharable, linked and exposed open data environment on the Semantic Web and has practical implications for bibliographic control and next-generation catalogues. With the increasing metadata initiatives (e.g., Virtual International Authority File) and registries like Open Metadata Registry[11] it is possible to interconnect with other data sets and linked systems by data linking. In order to reuse the metadata, the data should be built and aligned with open data principles, broader data models – Resource Description Framework and state of the art technology for software architecture and Web services modeling ontology to enable semantic web services:

- OAR-Complaint collections – OAISTER, OAI-ORE
- Scalable architecture – SOA, Cloud computing

[10] http://www.loc.gov/marc/transition/
[11] http://metadataregistry.org/

- Open protocols – REST, SOAP
- Semantic Web standards – RDF family, SKOS, OWL

5.1.4 Social Semantics

Folksonomies and crowdsourcing provide a conducive platform of collective intelligence in a collaborating environment where users have more power for generating metadata on a larger scale and social semantic digital libraries will evolve as collective knowledge systems (Gruber, 2008). Web 3.0 and social media brings in the potential of user-generated content and tagging, if mined and refined would yield better results of metadata for socializing Semantic Web. As the social semantics evolve Stock, Peters & Weller (2010) have examined as to how KOS are used externalizing implicit knowledge through Web 2.0 features in a corporate environment using intranets as knowledge managements tools. As the recommender system evolves in social Web, categorizing the social tags in folksonomies-based systems and their semantic relations can be mapped. Social semantics of subject metadata can be generated, enriched, refined from the user-generated content for improved retrieval.

6. Conclusion

As the Web is starting to offer services off the ground many Web applications and standards are exploring protocols such as SOAP and REST to generate Semantic Web Services. It is being rolled off with the emergent models like Web Services Modeling Ontology (WSMO) and rule languages like Web Service Modeling Language (WSML), Semantic Web Service Language (SWSL), Semantic Web Rule Language (SWRL), unleashing the potential of Web with 'Web of data'. However, the big challenge is how the Web can be embedded with underlying technologies and data semantics including descriptive schemas, modeling ontologies and description logics–which would facilitate a greater deal of machine-understandable, semantics-driven and interoperable metadata to start the Web services. Harnessing the potential of Web many forces pull together the realization of Semantic Web – metadata semantics, social semantics and ontologies. As the Semantic Web-based information services are projected promising enough for digital libraries to use interoperable metadata *'digital data'* has to be combined with *'Web of Data'*. It is important for all digital library developers to recognize the metadata schemes, data exchange models, and content standards for semantic digital libraries. Value-encoding schemes have to be created with the intent of planning to ensure the construction of high-quality metadata records for the future data exchange and broader Semantic Web-compliant data frameworks.

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