Ontologies as the most complex knowledge organization systems

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This article is intended to clarify, for those who are not familiar yet with them, the commonalities and specificities of knowledge organization systems (KOS) on the one hand and ontologies on the other, considering their common structural model and their shared purpose as tools assisting in the organization and retrieval of information. In other words its aim is to define what is common and what separates knowledge organization systems from ontologies and why converting former KOSs into ontologies is preferred. In the end interoperability issues are discussed.

Keywords: *knowledge organization systems, ontologies, semantic web, knowledge graphs, linked data*

1. Introduction

The first part of this article is devoted to the definitions of the main concepts used throughout the entire text and is meant to enable a clear perception of the terms and their scope. As the ongoing section of this article will prove, the double meaning of the word "ontology", one from metaphysics, and the other from computer science and information science congregates to show that information, proper to KOS, is converted into objects, or rather, digital objects as in ontologies. To quote Soergel (2009) "All KOS arise from the same conceptual basis, the representation of reality and thought through an entity-relationship schema". The purpose of this article is to demonstrate what is common and what separates knowledge organization systems and ontologies and how they can profitably value each other through future innovations using new technologies. Interoperability issues, a rather old concern of information specialists, assessing compatibility between knowledge organization systems, are presented at the end.

2. Definitions and scope of concepts used

The Oxford English Dictionary defines *ontology* as "The science or study of being; that department of metaphysics which relates to the being or essence of things, or to being in the abstract." The Merriam-Webster Dictionary (n.d.) gives two definitions of *ontology*: 1. "a branch of metaphysics concerned with the nature and relations of being; ontology deals with abstract entities" and 2. "a particular theory about the nature of being or the kinds of things that have existence".

In Wikipedia (2021) we find also a double meaning of ontologies as previously inferred: the definition of "*ontology* in computer science and information science, which encompasses a representation, formal naming and definition of the categories, properties and relations between the concepts, data and entities that substantiate one, many, or all domains of discourse". *Ontologies* arise out of the branch of philosophy called metaphysics, which deals with questions like "what exists?" and "what is the nature of reality?" This is concerned with exploring existence through properties, entities and relations such as those between particulars and universals, intrinsic and extrinsic properties, or essence and existence. As we shall see further, the existential nature of an ontology is the meaning borrowed from philosophy by the computer science and information science that sees information as an object.

For Gerhard Budin (2007) *knowledge organization* belongs to several different disciplines: "a part of information and library science, a part of philosophy of science and of epistemology, but also of knowledge management and knowledge engineering". In so saying he argues that knowledge organization's main purpose is the investigation and representation of knowledge structures based on the multitude of aspects it covers: from epistemological to cognitive science aspects, from linguistic and socio-cultural aspects (e.g. folk taxonomies), to historical aspects (e.g. administrative categorizations in ancient societies, history of science etc.). Knowledge organization, according to Budin, has also a practical side i.e. the creation and use of knowledge organization systems (KOS) and it is a crucial process in linguistic action by its result in text organization, regarding both reception and production.

A less intricate definition of knowledge organization comes from Brian Vickery who states that "to organize knowledge is to gather what we know into a comprehensive structure, to show its parts and their relationships" (Vickery 2012). In the *ISKO Encyclopedia of Knowledge Organization*, Maria Teresa Biagetti is citing Hjørland (2008) and Mazzocchi (2018) and concludes rather similarly, that *knowledge organization systems* are "tools for describing resources and aiding in the access and retrieval of documents and information" (Biagetti 2018).

Following Budin (2007) "knowledge organization systems cover all concept systems and terminologies used for ordering and retrieving knowledge (knowledge units, artifacts, etc.), such as: *classification systems, thesauri, indexing systems, taxonomies, nomenclatures and "ontologies"*. He makes a significant distinction between concepts and terms giving as argument the fact that one concept is rarely expressed by one word, the one-to-one correspondence between them being scarcely achieved. According to ISO 25964-1 (2011) a choice has to be made between several terms (or words) in order to express one concept. Hence indexing languages contain terms expressed by one or more words or phrases meantto label a conceptas a unit of thought.

Budin enumerates the *properties* of knowledge organization systems. In his view, a knowledge organization system has a conceptual structure, either hierarchical or non-hierarchical, it contains explicit presentation of conceptual links, providing term definitions in one or more languages, it is based on terminological and linguistic standardization, it is highly formalized and can be digital, particularly in the case of "ontologies". As to its size and form, it can have different sizes from small KOS to large ones (over 200.000 concepts), it can be static or dynamic (such as ontologies for modelling business processes in companies) and it can be provided with a visual structure and interactive user interface.

Therefore, knowledge organization systems are concept systems used for ordering and retrieving knowledge. This is what a double series of virtual classes organized at the initiative and by the expert management of the UK ISKO Chapter was about, starting in October 2020 and ending in February 2021, under the title *Knowledge Organization Education (KO-ED*). According to Aida Slavić, the program coordinator, the aim of these classes was "to encourage and support the next generation of Knowledge Organization researchers and practitioners, with attention to continuing professional development as well as basic education and training".

The reason why these series of classes are mentioned here is that many of their topics are closely related to the subject of the present paper. Each of the nine classes in the first track i.e. "Introduction to Knowledge Organization", plus the other eight classes in the second, "Theoretical perspectives in Knowledge Organization", were attended weekly by an average of 100 participants worldwide. Among others, they covered topics of our interestsuch as: definition and scope of KO in relation to Information Retrieval; content/subject analysis; general principles underlying knowledge organization systems; from concepts to knowledge organization systems; interoperability of KOS vocabularies.

When assigned indexing is used to represent subjects of documents, a choice has to be made between several words able to express the same concept (e.g. salary, wages, income). The contextual associations are displayed in the semantic relationships of the KOS vocabulary, including the form of terms (grammar and spelling) and their meanings. According to ISO 25964-1, the term that labels a concept can have two values: preferred (descriptor) or non-preferred.

This is one of the main particularities which separates a *flat vocabulary* (authority file, glossary, dictionary, gazetteer, code list) or a multi-level vocabulary (taxonomy), from a *relational or controlled vocabulary* (thesaurus, subject heading list, data model and ontology), as Sylvie Davies (2020) argued in her lecture. The controlled vocabulary enables the user to retrieve the most relevant documents to his information need.

In his tutorial on thesauri and ontologies, Soergel (2005) gives a simple but complete definition of a *thesaurus*, one of the main type of controlled vocabularies: "A thesaurus is a structured collection of concepts and terms for the purpose of improving the retrieval of information". He goes on saying that it provides "a semantic road map for searchers and indexers and anybody else interested in an orderly grasp of a subject field". For Soergel, a thesaurus structure goes far beyond the traditional functions it is commonly associated with, i.e. user-oriented indexing and information retrieval. Among those other functions the following are included: knowledge-based support for end user searching, support for meaningful information display, support for information seeking as an integral part of problem solving, learning and intellectual work, support for learning about any topic by providing learners with a coherent and appropriate conceptual framework, support in foreign language learning, readers assistance in understanding text, assistance in the combination of multiple databases or unified access to multiple databases.

With respect to the support provided by a thesaurus to information retrieval, Soergel enumerates a number of added functions: supports searching in multiple natural languages, both free text and indexing language searches in multiple databases, enables hierarchically expanded searching, mapping from the user query terms to descriptors used in a database or to the natural language expressions used in free text searching, mapping the query/indexing descriptors from one database to another.

In the mentioned tutorial, Soergel (2005) also talks about the *ontology* functions of a thesaurus among which we find the following: provide a semantic road map to individual fields and the relationships between and across fields, map out a concept space, relate concepts and terms across disciplines, languages and cultures, serve as reference tool, assist in consistent data collection and compilation of statistics (related to information analysis), provide a classification of diseases for diagnosis, of medical procedures for insurance billing, of commodities for customs and finally, a thesaurus is considered as an ontology for data element definition.

Currently, the term *ontology* has a quite imprecise definition being used for any knowledge organization system, mainly if defined according to Semantic Web standards, such as RDF. "Eventually, ontology was used to designate any classification, particularly in the communities of linguistics, AI and software engineering" says Soergel in his study devoted to the "landscape of Knowledge Organization Systems" (2009). *Topic maps, concept maps* and *knowledge graphs* should not be confused, as the author claims. According to Soergel, *topic maps* are semantic networks encoded following a standard, whereas *concept maps* are visual representations.

Following the RDF data model (https://www.w3.org/TR/rdf11-primer/#section-data-model), facts are seen in the form of *subject*, *predicate*, *object* (SPO) expression (triples), where subject and object are *entities* and predicate is the *relation* between them. In this case, the information:

"Leonard Nimoy was an actor who played the character Spock in the science-fiction movie Star Trek"
can be expressed via the following set of SPO triples:

Subject	Predicate	Object
(LeonardNimoy,	profession,	Actor)
(LeonardNimoy,	starredIn,	StarTrek)
(LeonardNimoy,	played,	Spock)
(Spock,	characterIn,	StarTrek)
(StarTrek,	genre,	ScienceFiction)

Knowledge graphs, as shown in Figure 1, are networks of entities, their semantic types, properties and relationships (Nickel et al. 2016).

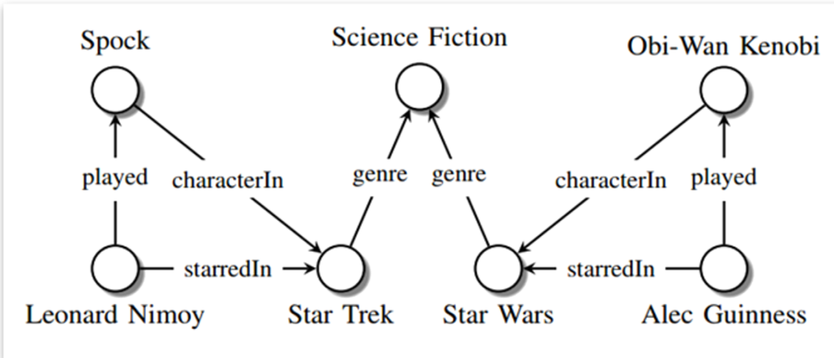

Figure 1. Sample knowledge graph
Source: Maximilian Nickel et al. *A Review of Relational Machine Learning for Knowledge Graphs: From Multi-Relational Link Prediction to Automated Knowledge Graph Construction*

In their turn, each of these triples can be combined to enter in a *multi-graph*, in which nodes represent entities (subjects and objects) and directed edges represent relationships. These relationships (edges) are always directed from the subject to the object and they are called differently (edge labels). Such constructions are called *knowledge graphs*. Additionally, while being collections of facts, knowledge graphs provide *type hierarchies* (e.g. Leonard Nimoy is an actor, therefore a person, who is a living thing) and *type constraints* (e.g. a person can only marry another person, not a thing) (Nickel et al. 2016).

To a more accessible understanding, a similar example is provided in the RDF data model Working Group Note of 24 June 2014 (https://www.w3.org/TR/rdf11-primer/#section-data-model), where, the same resource, Bob, is referenced in multiple triples:

```
<Bob><is a><person>.
<Bob><is a friend of><Alice>.
<Bob><is born on><the 4th of July 1990>.
<Bob><is interested in><the Mona Lisa>.
<the Mona Lisa><was created by><Leonardo da Vinci>.
<the video 'La Joconde à Washington'><is about><the Mona Lisa>
```

Bob is the subject of four triples and in the same context, Mona Lisa, while being the subject of the fifth, is also the object of the fourth and the sixth. The ability for a resource to be in the subject position of one triple and also in the object position of another, enabling the connections between triples, makes one of the strong points of the RDF model. This feature opens the way towards acquiring new knowledge.

Many definitions were given to knowledge graphs, out of which Ehrlinger & Wöss (2016) selected four in their article. Of those, the simplest and also clearest of them is one authored by Krötzsch & Weikum (2016): “Knowledge graphs are large networks of entities, their semantic types, properties, and relationships between entities.” Ehrlinger and Wöss give their own definition which is also applicable to our purposes and introduces the relationship between knowledge graphs and ontologies. “A knowledge graph acquires and integrates information into an ontology and applies a reasoner to derive new knowledge”.

Knowledge graphs are used in applications such as: DBpedia, YAGO (Yet Another Great Ontology – a large knowledge base of general knowledge about people, cities, countries, movies and organizations), Freebase and Wikidata, to mention only a few. The common element of these applications is their use of *Linked Data*.

As Bizer et al. (2009) posit, *DBpedia* project is "a community effort to extract structured information from Wikipedia and to make this information accessible on the Web". The knowledge base emerging as a result comprises and describes 2.6 million entities. including human-readable definitions in 30 languages, relationships to other resources, classifications in four concept hierarchies, various facts as well as data-level links to other Web data sources describing the entity. The subjects included in the DBpedia knowledge base cover "geographic information, people, companies, films, music, genes, drugs, books and scientific publications."

Following Bizer et al. (2009) the term *Linked Data* refers to "a set of best practices for publishing and connecting structured data on the Web", meant to create what is called the Web of Data. Hence, the global data space is connecting data from diverse domains such as people, companies, books, scientific publications, films, music, television and radio programs, genes, proteins, drugs and clinical trials, online communities, statistical and scientific data and reviews.

An expressive example of linked statistical datasets is shown in Figure 2.

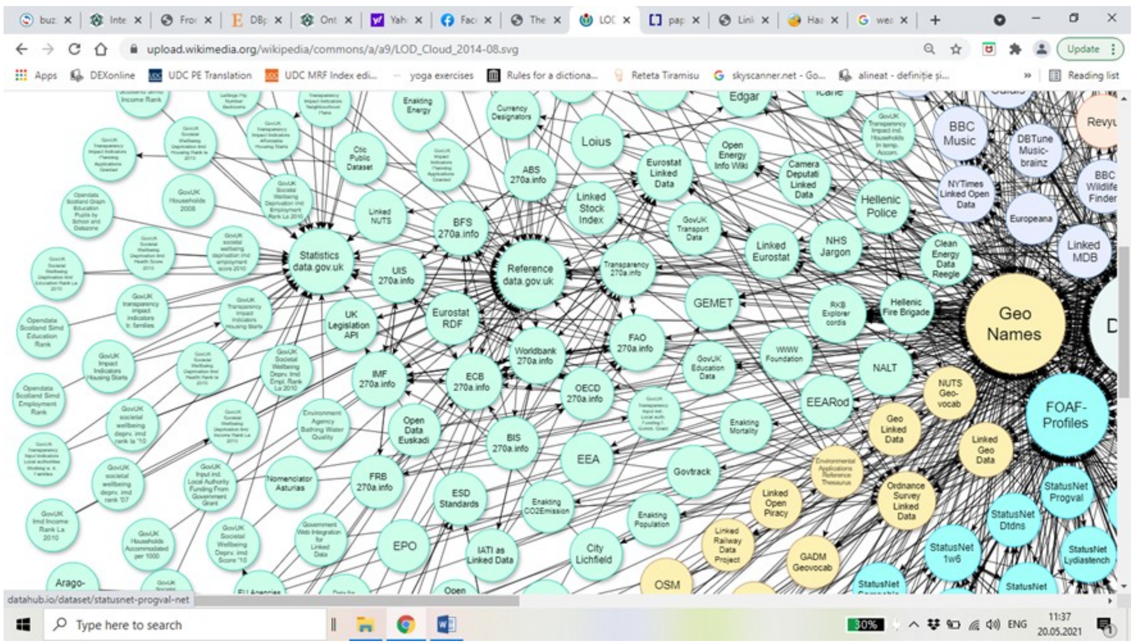

Figure 2. Linked Datasets as of August 2014

Source: https://upload.wikimedia.org/wikipedia/commons/a/a9/LOD_Cloud_2014-08.svg

As one points on any of the nodes in this diagram, one finds the information labelled on it and the links go on, expanding the search to the point where the desired information is found, such as: The administrative geography and civil voting area ontology: an ontology describing the administrative and voting area geography of Great Britain.

Traditional Knowledge Organization Systems may also be regarded as possible linked open data. The UDC Summary, an abbreviated multilingual open source version of the Universal Decimal Classification, meant for education purposes has been available as linked data since 2011 (http://www.udcsummary.info/about.htm).

This was reported at an International UDC Seminar by Freire (2015) from The European Library, who talked about linking subject data, particularly, about the alignments between ontologies. Alignments, or interoperability among KOSs as currently labelled, between subject data included projects like: CERIF, MACS (RAMEAU, SWD, LCSH), but were also expected for classification systems like UDC and DDC. At that moment, only shallow linking was accomplished for the most general classifications. Linking classifications to LOD datasets, he said, was not as straight forward due to pre-combined classification codes.

Following Slavić (2019) experiments have been made to explore the potential of the full UDC edition as linked data to the benefit of both libraries and KOS communities. The UDC ontology should better support automation, expansion and maintenance of the classification and also publishing and translating services and its uniform use. RDF generated solutions should be available for parsing, validation and URIs for the UDC codes. As Slavić posits, "UDC RDF triple store should contain all data necessary to resolve and interpret strings coming from library catalogues (including historical UDC data)".

Among the potentials of using the UDC as linked data, Slavić enumerates: the alignment of subject data with the latest knowledge organization tools, without libraries having to re-index, re-classify or re-organize collections, the assistance in discovery of knowledge in heritage collections via subject data (data mining), the support for interpreting, validating and enriching and serving back enhanced subject data to libraries.

3. What is common and what separates knowledge organization systems (KOSs) from ontologies

Following Budin (2007), library science and information science operate with knowledge organization systems as tools for information ordering and retrieval, whereas computer science are more specifically working within the frame of digital libraries using ontologies and knowledge engineering. While terminologies are more or less structured collections of concepts and terms in one (or more) language(s) in a specific subject field, he argues, ontologies are "formal, explicit (conceptual) models of object ranges in a computational representation". Albeit there are differences particularly in the structure and treatment of subject data, there are also commonalities between the two, as they are methods of organizing knowledge. Budin postulates that all structured terminology systems: classifications, thesauri, taxonomies, nomenclatures–can be "ontologized".

Conceptualization is specific to and differentiates KOSs from ontologies (Gruber 1993). According to Biagetti (2018), conceptualization is "a synthetic view of the world according to some purposes, a conceptual representation of a specific field of knowledge that represents *concepts, entities, objects* and *relations* among them by specifying the links between those concepts, objects, events and entities, pertaining to a field of interest."

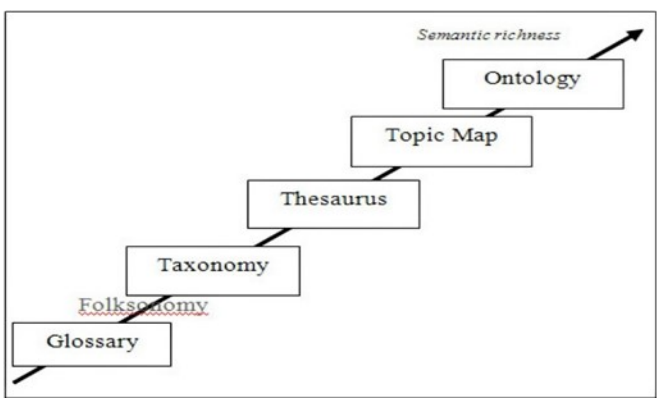

Figure 3. The semantic staircase (Olensky 2010)

KOSs are structured collections of systematically organized concepts and have semantic relations between the terms representing the concepts. The richer semantic relations and more control on terms, the more efficient the retrieval of information.

As shown by the diagram in Figure 3, the *semantic richness* is another separating criterion between KOSs and ontologies, one that places them on top of the *semantic staircase* going from glossaries through thesauri and ending with ontologies (Olensky 2010).

The multiple relationship types are defined in a NISO standard (2005) for thesaurus construction focusing on "controlled vocabularies that are used for the representation of content objects in knowledge organization systems including *lists, synonym rings, taxonomies and thesauri*. One of the three main vocabulary control methods recommended by the standard is to link synonyms and near synonyms. Soergel (2005) mentions several synonymous term type relationships such as:

ST Synonymous Term
ET Equivalent Term
SP Spelling Variant
AB Abbreviation
FT Full Term

In digital libraries, the expansion of query terms have as result a better precision. To this purpose *WordNet*, a semantic network for the English language was created by the Cognitive Science Laboratory of Princeton University, under the supervision of George Miller (2007), as reported by Biagetti (2018). Without being an ontology, WordNet is rather a dictionary based on semantic structure, built on the model of Roget's Thesaurus. It includes nouns, adjectives and adverbs organized in *synsets* (sets of synonymous terms). Each synset is dedicated to a concept which forms *semantic networks* through its relationships of meronymy, hyperonymy, antonymy and hyponymy.

Besides, the conceptual model Functional Requirements for Subject Authority Data (2010) mentions ten categories of associative relationships such as: *Cause / Effect* (accident / injury); *Process / Agent* (velocity measurement / speedometer); *Action / Product of the action* (weaving / cloth), to mention a few. The related term (RT) thesaurus specific relation is coined by Hjørland (2015) as "unspecified semantic relations" including antonyms, cause-effect relations or sequences of facts, more accurately defined in ontologies.

The actual feature that differentiates ontologies from (other) KOSs is the capacity of the former to represent a greater number of semantic relations, and, as suggested by Zeng (2021), to offer more attributes for each class.

4. Interoperability issues

Since we currently witness a growing number of data bases, information retrieval systems, websites that use controlled vocabularies for subject retrieval, it became important to facilitate interoperability between the KOS vocabularies. ISO 25964-2 (2013) describes, compares and contrasts the elements and features of these vocabularies that are involved when interoperability is needed. It gives recommendations for the establishment and maintenance of mappings between multiple thesauri, or between thesauri and other types of vocabularies.

According to Zeng (2019), compatibility between knowledge organization systems has been the concern of information specialists much earlier than now. Compatibility issues, so much like interoperability nowadays made their preoccupation at the turn of the century. MACS or Multilingual Access to Subjects was a pioneer project aimed to enable users to simultaneously search the catalogues of the project's partner libraries in the languages of their choice (English, French and German). MACS, a distributed project of CoBRA+ working group (Computerized Bibliographic Record Actions) was concerned with mapping of terms and subject heading strings via links between the participating subject heading systems: RAMEAU, SWD/RSWK and LCSH (Frâncu 2003).

Zeng (2021) talked on the same ISKO UK series of lectures mentioned before, about the necessity of interoperability between data and information systems especially in the digital information environment, not only for professions dealing with information resources, but also businesses, organizations, research groups, and individuals, in order to optimize experiences, minimize efforts and costs and drive future innovations utilizing new technologies and resources (Fritzsche et al. 2017).

Interoperability, as defined in ISO 25964-2 (2013), is the "ability of two or more systems or components to exchange information and to use the information that has been exchanged". When talking about interoperability, the problems at issue fall into four categories: system (data presentation), syntactic (data language) semantic (data context), structural (data architecture). All these problems are discussed in details by Zeng (2019) with much attention awarded to the multiple examples of differently built ontologies.

5. Conclusions

To sum up, the conceptual structure of a knowledge organization system be it hierarchical or non-hierarchical, contains explicit presentation of conceptual links, providing term definitions in one or more languages, it is based on terminological and linguistic standardization, it is highly formalized and can be digital particularly in the case of ontologies. Ontologies can have different sizes, can be static or dynamic (such as ontologies for modelling business processes in companies) and it can be provided with a visual structure and interactive user interface. In addition to this, their use goes far beyond those of KOSs through integration across systems, virtual harmonization (FAST, Viaf), vocabulary repositories or domain-oriented portals.

To conclude, it can only be agreed with Biagetti on the important role that ontologies played in the construct of the Semantic Web in the original vision by Berners-Lee, on their relevance as semantic interoperability schemes and on their effectiveness in the building of linked open data. There are ontology repositories that host formal ontologies and other KOS converted to ontology using required formats such as OWL. According to Zeng, vocabulary registries, unlike repositories, offer information about vocabularies (i.e. metadata) instead of the vocabulary contents themselves; they are the fundamental services for locating KOS products, such as BARTOC (Basel Register of Thesauri, Ontologies & Classifications), LOV (Linked Open Vocabularies including over 600 registered vocabularies and Data Hub's, the largest registry, with over 11,270 datasets registered.

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