

The Simple Knowledge Organization System (SKOS)

A situation report for the HIVE Project

November 2008

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1. INTRODUCTION

Context: The HIVE Project

This report has been carried out in the context of the project HIVE (Helping Interdisciplinary Vocabularies Engineering), conducted by the Metadata Research Center of the School of Library and Information Systems, University of North Carolina at Chapel Hill and founded by the Institute of Museum and Library Services (ILMS).

The project aims to help the development of a controlled vocabulary for the Dryad repository. This repository hosts the data underlying published works in evolutionary biology. This is a highly interdisciplinary field drawing from a wide range of scientific disciplines, including ecology, developmental biology, genetics, molecular biology, paleontology, and systematic. A preliminary study that extracted the subjects and keywords of the resources in the repository and tried to map them to several controlled vocabularies indicated that a single controlled vocabulary cannot represent the interdisciplinary of the evolutionary biology.

To address these needs, and noted controlled vocabularies limitations, the HIVE (Helping Interdisciplinary Vocabulary Engineering) has been proposed, aiming to develop an automatic metadata generation approach that dynamically integrates discipline specific controlled vocabularies and assists content creators (or professionals) with subject cataloging. The Simple Knowledge Organization System (SKOS) has been selected to assist the integration of vocabularies in this approach.

Purpose

In order to help the researchers of the HIVE project in the application of SKOS for the purposes of the project, some literature and web resources review has been carried out. This review has focused in the compilation of selected papers, presentations and other documents related to SKOS and its development and the initiatives that have adopted this specification.

Moreover, the various projects, tools and SKOS data described and mentioned in these resources have been gathered and categorized. This task has enabled the identification of the achievements already made by others initiatives with similar particular needs that those addressed by the Dryad repository in relation with semantic interoperability, and thus will help in the achievement of the HIVE project objectives.

Content and sections

The next five sections of the present document summarize the work done in this SKOS literature review and information gathering.

Firstly, we present a brief introduction to the SKOS initiative, focusing in its purpose, status and the intellectual responsibility of its development. It includes a relation of the main information sources available on line about SKOS, as well as the normative and supportive documents, like the specification, guides, recommendations and others. Furthermore, the basics of the SKOS model, extracted from the SKOS Primer document, are presented.

Secondly, the relation and role of SKOS in the achievement of semantic interoperability is analyzed. We reflect about the opportunities and limitations of SKOS in this sense.

The third section offers a selection of literature about SKOS and its applications. The papers selected are presented in two tables:

- The first table contains the main papers about the SKOS model, distinguishing between those papers merely introducing or presenting the model and those that reflect about the foundations of the model or about its development and future improvement.
- The second table contains more than 20 papers related to SKOS implementations at various levels and from different points of view. In this way, we have categorized the papers in 3 groups: papers about the representation and conversion of vocabularies to the SKOS model; papers about the alignment of vocabularies or concept schemes by the means of SKOS; and papers about the implementation or development of applications for the indexing and retrieval of resources with vocabularies in SKOS.

The fourth section draws a panorama of the several initiatives related to SKOS in different aspects, some of them presented in the papers mentioned in the previous section and others already collected in the SKOS official webpage and development wiki. These initiatives have been synthesized in four areas, namely: a list of specific projects and particular implementations of SKOS; a list of tools and applications compliant with the SKOS model, classified in terms of the task that they support in the vocabulary workflow; a compilation of SKOS data in the sense of vocabularies expressed in the SKOS model and openly available online; and finally, a selection of the main organizations, research institutions, groups or individuals that contribute to (or interested in) the development of SKOS, consolidating and widening its scope.

Finally, the fifth section presents a selection of those initiatives, tools, data and other achievements that could help the HIVE project researchers to accomplish the objectives and tasks necessities for the building of HIVE, mainly for the vocabulary preparation and the vocabulary server development phases.

The list of bibliographic references of the papers mentioned in section 4 and other complementary bibliography is included at the end of the report.

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Contributors

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2. SKOS (Simple Knowledge Organization Systems)

This section serves as a simple introduction to the SKOS initiative, briefly explaining its purpose, status and intellectual responsibility of its development.

It also presents the main sources of information available on line about SKOS, synthesizing the content provided by them, and specially referring to the SKOS normative and informative documents (specification, guides, recommendations and others).

Finally, the basics of the SKOS model, extracted from the SKOS Primer document, are presented in order to enable the understanding of the concepts mentioned in the following sections.

2.1. What is SKOS

SKOS is an area of work developing specifications and standards to support the use of knowledge organisation systems (KOS) such as thesauri, classification schemes, subject heading systems and taxonomies within the framework of the Semantic Web.

SKOS provides a standard way to represent knowledge organisation systems using the Resource Description Framework (RDF). Encoding this information in RDF allows it to be passed between computer applications in an interoperable way.

The main concepts and components of the SKOS model, as well as its uses and benefits, are explained in the section 2.5 of this report.

2.2. Who develops and contributes to SKOS

SKOS is an open collaboration initiated by the Semantic Web Advanced Development for Europe project (SWAD-Europe), funded by the EU-IST 5th framework program and initiated in 2003. SWAD-E aimed to develop specifications and standards to support the use of knowledge organisation systems (KOS) on the semantic web.

Since 2004, the development of SKOS continued within the W3C's Semantic Web Best Practices and Deployment Working Group (SWBPD-WG), now named the Semantic Web Deployment Working Group (SWDWG).

The development and design of SKOS is an open and collaborative task, enriched with the contribution of users (for example, with the submission of use cases requirements) and with the continuous discussion in the mailing list (public-esw-thes@w3.org).

2.3. Information sources about SKOS

There are two main sources of information available on line about SKOS, both in the framework of the W3C website: the SKOS official webpage and the SKOSDev Wiki.

SKOS Website - <http://www.w3.org/2004/02/skos/>

SKOS official webpage is integrated in the Semantic Web Activity, within the W3C website.

The main sections with useful content are:

1. **Introduction** (brief explanation of SKOS, its relation with RDF, who develops it, status and how to contribute).
2. **Development & Participation** (some explanation of the SDWDG as the SKOS developer and the open participation by the mailing list).
3. **Specifications & Documentation** (at a Last Call Stage status: SKOS Reference; and working drafts status: SKOS Primer, SKOS Use cases & requirements, SKOS Core Guide, SKOS Core Vocabulary Specification).
4. **RDF Vocabularies** (current SKOS Vocabulary and SKOS eXtension for Labels (XL) Vocabulary, and the deprecated vocabularies).
5. **Use Cases, & Requirements** (the SDWDG sent a questionnaire to a wide audience, to gather representative use cases; the derived requirements have influenced the development of SKOS).
6. **Tutorials, Presentations & Papers** (<20 docs, mainly by the members of the SDWDG);
7. **Validation Service (alpha)**: online tool to validate the RDF document of an SKOS vocabulary, in its 3 different syntaxes (RDF/XML, Notation3/Turtle, N-triples).
8. **Translations**: labels, comments and definitions for the classes and properties of the SKOS Core Vocabulary are available in RDF in English, French, Dutch, German, Portuguese, Italian and Chinese). Also some documentation is in several languages.
9. **Version history** (track of specifications, documents, guides, namespaces, RDFs, since 2003).

The rest of the sections in the SKOS official webpage forward to the SKOSDev area of the ESW Wiki (<http://esw.w3.org/topic/FrontPage>).

ESW Wiki - SKOSDev - <http://esw.w3.org/topic/SkosDev>

The other main source of information is the SKOSDev a wiki area in the ESW Wiki for collaborative work on SKOS schemas and APIs, supporting documentation and resources.

The most part of this wiki is still in construction. Some of the more valuable sections are the following:

- [DataZone](#): community page for links to SKOS-RDF data. It offers almost 20 links in about 12 data initiatives, including blogs and thesaurus, categories, glossaries or terminologies in

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SKOS. [It is incomplete; see section 5.3. in this document for more comprehensive SKOS data list].

- [ToolShed](#): links to tools for working with SKOS. 12 tools now, including thesaurus authoring tools, conversion tools, indexing and annotation tools, RDF mapping tools, the SKOS validator and other scripts or plugins. [It is incomplete; see section 5.2. in this document for more comprehensive SKOS data list].
- [Mappings](#): mapping projects (7) and tools (2) for the integration of different Knowledge Organization Systems like thesauri and classification. Some of them are previous to SKOS and most of them don't necessarily use the SKOS vocabulary.
- [Relevant Companies and Organizations](#) : 4 commercial, 4 academic, 3 government & public, 4 Charity and Non-profitable organizations. [For a detailed relation of companies and organizations working with SKOS, see section 5.4].

Other interesting sections in the SKOSDev Wiki, but with scarce information yet are those related to the representation of classifications ([/ModelClassifications](#)) and Authority Files ([/AuthorityFiles](#)) with SKOS, or the issues related to SKOS and OWL-DL ([/SkosOwldl](#)).

The rest of the SKOSDev Wiki sections are actually more addressed to the SKOS developers and contributors than to the end users.

2.4. SKOS Specifications & Documentation

The SKOS Specifications can be found at the SKOS official webpage (<http://www.w3.org/2004/02/skos/specs>).

These specifications are currently published as W3C Working Drafts, which means that they are work in progress. Only the SKOS Reference is at the Last Call stage of the W3C Recommendation Track process, since August 2008.

The currently active documents are the followings:

- [SKOS Primer](#)
W3C Working Draft 21 February 2008. Antoine Isaac and Ed Summers eds.
- [SKOS Reference](#)
W3C Working Draft 29 August 2008. Alistair Miles and Sean Bechhofer eds.
- [SKOS Use Cases and Requirements](#)
W3C Working Draft 16 May 2007. Antoine Isaac, Jon Phipps, Daniel Rubin eds
- [Quick Guide to Publishing a Thesaurus on the Semantic Web](#)
W3C Working Draft 17 May 2005. Alistair Miles ed.

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The deprecated documents (created in 2005 in the beginning of SKOS) are also available in this section: the [SKOS Core Guide](#), which has been superseded by the [SKOS Primer](#); and the [SKOS Core Vocabulary Specification](#), superseded by the [SKOS Reference](#).

The [SKOS Primer](#) is an informative and introductory document to SKOS, a user guide for those who would like to represent their concept scheme using SKOS. It explains the main concepts of SKOS or SKOS essentials, as well as the utility of SKOS in the networking of Knowledge Organization Systems on the Semantic Web. It presents two levels of application of SKOS, basic and advanced, and the option of combining SKOS with other modelling approaches. This document is non normative, and is a companion of the normative document, the [SKOS Reference](#).

The [SKOS Reference](#) is the normative specification of the Simple Knowledge Organization System. It is intended for readers who are involved in the design and implementation of information systems, and who already have a good understanding of Semantic Web technology, especially RDF and OWL. Following an Introduction to the SKOS model, including background and motivation, the SKOS Reference defines the components of the model, namely: SKOS Namespace and Vocabulary, skos:Concept class, concept schemes, lexical labels, notations, document (note) properties, semantic relations, concept collections, mapping properties and references.

The [SKOS Use Cases and Requirements](#) is a non-normative document that presents the preparatory work for the 2008 version of SKOS. It lists representative use cases, which were obtained after a dedicated questionnaire was sent in 2007 to a wide audience. It also features a set of fundamental or secondary requirements derived from these use cases, which have been used to guide the design of SKOS. Most of the use cases are related to active projects, even if some have not implemented the SKOS model yet. The more interesting ones have been included in the compilation of SKOS related projects presented in section 5.1 of this report.

Finally, the [Quick Guide to Publishing a Thesaurus on the Semantic Web](#) is a non-normative document that intends to offer some guidelines to the projects about how to express the content and structure of a thesaurus, and metadata about a thesaurus, in RDF, and using the SKOS vocabulary when possible.

This document is based in a previous and deprecated one, [Migrating Thesauri to the Semantic Web. Guidelines and case studies for generating RDF encodings of existing thesauri](#), which also included three case studies (APAIS Thesaurus, English Heritage Aircraft Type Thesaurus, and GEMET) not included in the current guide.

2.5. SKOS basic notions

SKOS—Simple Knowledge Organization System—provides a model for expressing the basic structure and content of concept schemes such as thesauri, classification schemes, subject heading lists, taxonomies, folksonomies, and other similar types of controlled vocabulary. As an application of the Resource Description Framework (RDF), SKOS allows concepts to be composed and published on the World Wide Web, linked with data on the Web and integrated into other concept schemes.

Two levels of implementation of SKOS can be considered:

- In basic SKOS, conceptual resources (concepts) are identified with URIs, labelled with strings in one or more natural languages, documented with various types of note, semantically related to each other in informal hierarchies and association networks, and aggregated into concept schemes.
- In advanced SKOS, conceptual resources can be mapped across concept schemes and grouped into labeled or ordered collections. Relationships between concept labels can be specified. Finally, the SKOS vocabulary itself can be extended to suit the needs of particular communities of practice or combined with other modeling vocabularies.

SKOS has been designed to provide a low-cost migration path for porting existing organization systems to the Semantic Web. SKOS also provides a lightweight, intuitive conceptual modeling language for developing and sharing new knowledge organization systems (KOSs). It can be used on its own, or in combination with more formal languages like the Web Ontology Language (OWL) [OWL]. SKOS can also be seen as a bridging technology, providing the missing link between the rigorous logical formalism of ontology languages such as OWL and the chaotic, informal and weakly-structured world of Web-based collaboration tools, as exemplified by social tagging applications.

The main components of the SKOS model or **SKOS Essentials** are: Concepts, Labels, Semantic Relationships, Documentary Notes and Concept Schemes.

The [SKOS Reference](#) document summarizes very well the relation of the components of the SKOS Model in the following paragraph:

“Using SKOS, **concepts** can be identified using URIs, **labeled** with lexical strings in one or more natural languages, assigned **notations** (lexical codes), **documented** with various types of note, **linked to other concepts** and organized into informal hierarchies and association networks, aggregated into **concept schemes**, grouped into labeled and/or ordered **collections**, and **mapped** to concepts in other schemes”.

Below we present some extracts of the [SKOS Primer](#) document explaining briefly each statement highlighted in the synopsis paragraph.

Concepts

Fundamental element of the SKOS vocabulary. Concepts are the *units of thought*—ideas, meanings, or (categories of) objects and events—which underlie many knowledge organization systems [[SKOS-UCR](#)]. As such, concepts exist in the mind as abstract entities which are independent of the terms used to label them. The class [skos:Concept](#) allows implementors to assert that a given resource is a concept.

Labels

Expressions that are used to refer to the concepts in natural language.

SKOS provides three properties to attach labels to conceptual resources: [skos:prefLabel](#), [skos:altLabel](#) and [skos:hiddenLabel](#). Each property implies a specific status for the label it introduces, ranging from a strong, univocal denotation relationship, to a string to aid in lookup. These properties are formally defined as being pairwise disjoint. This means, for example, that it is an error if a concept has a same literal both as its preferred label and as an alternative label.

Semantic Relationships

In KOSs *semantic relations* play a crucial role for defining concepts. The meaning of a concept is defined not just by the natural-language words in its labels but also by its links to other concepts in the vocabulary. Mirroring the fundamental categories of relations that are used in vocabularies such as thesauri [[ISO2788](#)], SKOS supplies three standard properties:

- [skos:broader](#) and [skos:narrower](#) enable the representation of hierarchical links, such as the relationship between one *genre* and its more specific *species*, or, depending on interpretations, the relationship between one *whole* and its *parts*;
 - Notes: Implicit statements // Transitive vs. Non-transitive
- [skos:related](#) enables the representation of associative (non-hierarchical) links, such as the relationship between one type of *event* and a category of entities which typically *participate* in it. Another use for [skos:related](#) is between two categories where neither is more general or more specific. Note that [skos:related](#) enables the representation of associative (non-hierarchical) links, which can also be used to represent part-whole links that are not meant as hierarchical relationships.
 - Note—(non-)transitivity of; mixing hierarchy with association

Documentary Notes

Next to the semantic relationships structured characterizations, concepts sometimes have to be further defined using human-readable ("informal") documentation, such as *scope notes* or *definitions*. SKOS provides a [skos:note](#) property for general documentation purposes, which is

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further specialized into `skos:scopeNote`, `skos:definition`, `skos:example`, and `skos:historyNote` to fit more specific types of documentation.

- [skos:scopeNote](#) supplies some, possibly partial, information about the intended meaning of a concept, especially as an indication of how the use of a concept is limited in indexing practice.
- [skos:definition](#) supplies a complete explanation of the intended meaning of a concept.
- [skos:example](#) supplies an example of the use of a concept.
- [skos:historyNote](#) describes significant changes to the meaning or the form of a concept.

In addition to these notes that are intended for users of a concept scheme, SKOS includes two specializations of `skos:note` that are useful for KOS managers or editors: `skos:editorialNote` and `skos:changeNote`.

- [skos:editorialNote](#) supplies information that is an aid to administrative housekeeping, such as reminders of editorial work still to be done, or warnings in the event that future editorial changes might be made:
- [skos:changeNote](#) documents fine-grained changes to a concept, for the purposes of administration and maintenance

Concept Schemes

Concepts can be created and used as stand-alone entities. However, especially in indexing practice, concepts usually come in carefully compiled vocabularies, such as thesauri or classification schemes. SKOS offers the means of representing such KOSs using the [skos:ConceptScheme](#) class.

Define a concept scheme resource (representing a thesaurus) and to describe that resource using the [dc:title](#) and [dc:creator](#) properties from Dublin Core [[DC](#)]. Once the concept scheme resource has been created, it can be linked to the concepts it contains using the [skos:inScheme](#) property. Finally, for providing an efficient access to the entry points of broader/narrower concept hierarchies, SKOS defines a [skos:hasTopConcept](#) property. This property allows you to link a concept scheme to the (possibly many) most general concepts it contains

Collections of concepts

SKOS allows the definition of meaningful groupings or "collections" of concepts. In thesaurus terminology these collections are known as "arrays", and the term that groups the terms in the collection is a "node label".

To correctly model such concept collection structures, SKOS introduces a [skos:Collection](#) class. Instances of this class group specific concepts by means of the [skos:member](#) property.

Mapping concept schemes

SKOS provides several properties that map concepts between different concept schemes. This can be done by asserting that two concepts have a similar meaning, using the [skos:exactMatch](#) and [skos:closeMatch](#) properties. Two concepts from different concept schemes can also be mapped using properties that parallel the semantic relations introduced in Section 2.3: [skos:broadMatch](#), [skos:narrowMatch](#) and [skos:relatedMatch](#).

2.6. Usefulness of SKOS

Jointly with the SKOS basic description and notions, the SKOS Primer approaches directly or indirectly the main usefulness of the SKOS model. The scope of the usefulness of SKOS will depend in the level of implementation (basic or advanced) and the specific features applied. The main uses are summarized as follows:

- [Vocabulary representation and publishing](#)

Obviously, the main feature of SKOS is the provision of a model for [expressing](#) the basic structure and content of concept schemes such as thesauri, classification schemes, subject heading lists, taxonomies, folksonomies, and other similar types of controlled vocabulary.

In this sense, SKOS enables the migration of already existing controlled vocabularies and the creation of new ones, using a common and standardized [representation](#) model. As an application of the Resource Description Framework (RDF), SKOS allows the [publication](#) of vocabularies on the World Wide Web.

- [Subject Indexing and Retrieval](#)

SKOS can be used for the [indexing of resources](#) in an information system, creating links between concepts in a KOS and resources, annotating documents with conceptual units which define their subject. While the SKOS vocabulary itself does not include a mechanism for associating an arbitrary resource with a concept in SKOS, implementors can turn to other vocabularies, linking the subject metadata elements in their scheme (like `dc:subject` in Dublin Core) with an `skos:Concept`.

The subject indexing facilitates in last instance the [Retrieval](#) of resources in an information system through subject queries and subject browsing. Moreover, in the case of several information systems using the same vocabulary, SKOS allows a common way of vocabulary representation, thus, a common mechanism of subject indexing and retrieval. In this way, a [federated search](#) of these systems, using controlled and structured vocabularies, can be easily implemented.

- [Vocabulary alignment](#)

SKOS allows the interlinking of concept schemes by the means of concept mapping. This can be done by asserting that two concepts in different concept schemes have a similar meaning [using the `skos:exactMatch` and `skos:closeMatch` properties], or establishing semantic relationships between concepts [`skos:broadMatch`, `skos:narrowMatch` and `skos:relatedMatch`].

This feature can be useful in the networking of Knowledge Organization Systems. As concepts from different concept schemes are connected together they begin to form a distributed, heterogeneous global concept scheme.

Also, taken into account the subject indexing and retrieval capabilities of SKOS, it will help in the [retrieval](#) of resources both in a unique system using multiple vocabularies and enabling a [federated search](#) through several systems using distinct vocabularies.

3. SEMANTIC INTEROPERABILITY & SKOS

Definitions and dimensions of interoperability

There currently exist multiple definitions of interoperability, but the most cited one is the definition given by the IEEE in 1990: *“the ability of two or more networks, systems, devices, applications, or components to exchange information between them and to use the information so exchanged”*.

Another interesting definition is suggested by the Interoperability Technical Framework (ITF) of the Australian Government, which defines the interoperability in the context of Information Technologies and organizations, as *“the ability to transfer and use information in a uniform and efficient manner across multiple organizations and information technology systems. It underpins the level of benefits accruing to enterprises, government and the wider economy through e-commerce”* [AGIMO 2005].

In the same line, the European Interoperability Framework for Pan-European eGovernment Services [IDABC 2004], reference document which provides recommendations and defines generic standards with regard to organizational, semantic and technical aspects of interoperability for eGovernment in Europe, published by the European program IDABC (Interoperable Delivery of European eGovernment Services to public Administrations, Businesses and Citizens) as follows: *“Interoperability means the ability of information and communication technology (ICT) systems and of the business processes they support to exchange data and to enable the sharing of information and knowledge”*.

But in order to achieve the use and understanding of the information exchanged as implied in the previous definitions, needs specific interoperability mechanisms. As many authors and initiatives have already considered, the interoperability has many different dimensions, being the most commonly referred the technical, semantic, and organizational.

The semantic aspect of interoperability, as the IDABC states *“is concerned with ensuring that the precise meaning of exchanged information is understandable by any other application that was not initially developed for this purpose. Semantic interoperability enables systems to combine received information with other information resources and to process it in a meaningful manner”*.

Therefore, the semantic interoperability is the main aspect that facilitates the appropriate use and understanding of information and knowledge between information systems and organizations.

The achievement of semantic interoperability is considered one of the biggest challenges for the integration of information systems. Basically, this is due to the fact that meaning changes by context and over time and different requirements in different domains result in different information models. As described in QUALIPSO [Lange 2008], the issue of semantic interoperability appears in two communication contexts: human-to-machine and machine-to-machine context. In

the second context, where various information systems have to inter-operate, several dimensions can be considered: *structural* and *representational* incompatibilities in concept modeling, *linguistic* incompatibilities like the use of the same term but different concept, or different term but same concept; and *conceptual* incompatibilities, when concept of different knowledge systems have some overlap in their meaning.

A common mechanism to ensure the correct interpretation of data exchanged between systems is the usage of a common terminology developed and made available to the systems by humans who agreed on the mental representation of each element. By means of controlled vocabularies semantic interoperability can be established. However, in order to allow systems to understand exchanged information in a more dynamic way the sole use of controlled vocabularies is not sufficient. Semantically richer knowledge models, such as taxonomies and ontologies, which define the concepts for a certain domain as well as their relations, are necessary.

Interoperability enhancement with SKOS

The Simple Knowledge Organization System, as a standard model to represent controlled vocabularies for the semantic web, can be considered the first step in the achievement of semantic interoperability. SKOS deals with representational and conceptual heterogeneity, enabling the transfer and sharing of vocabularies between different systems and also the sharing of meaning between systems using distinct vocabularies. Moreover, the use of a common mark-up language like XML and a common representation framework as RDF ensures the interoperability of vocabularies at a technical (use of XML file format) and syntactic level.

The key features of SKOS for the achievement of the semantic interoperability are categorized below depending on whether one or multiple vocabularies are used.

Using the same vocabulary:

- Sharing of a common syntactic representation of concepts and structure in a standardized way using RDF.
- Sharing of a common subject indexing and retrieval mechanism.
- Re-using and extension of concept schemes (each concept has one URI)¹, maintaining the interoperability at the basic level

Using several or distinct vocabularies:

- Connecting concept schemes to create a distributed heterogeneous concept scheme.
- Mapping concept schemes and establishing relations between existing concepts.

¹ Re-using and extending concept schemes in SKOS is possible because each concept has one URI. This means that it could be used in several concept schemes at the same time. It allows the use of concepts of a specific concept scheme as a basis, without needing of recreation, adding only the concepts needed for local purposes.

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- Subject Indexing with the more accurate vocabulary for each resource or collection, or using several vocabularies at the same time.
- Federated subject search and subject browsing through several systems or collections. Thanks to the relations established between concepts, the query terms introduced by the users can be mapped to the different vocabularies used for indexing each resource.

Therefore, SKOS can help in the achievement of semantic interoperability of information systems that use either the same or different vocabularies in the subject indexing of their resources. Furthermore, it is the base of the retrieval, enabling the search and browsing of distributed vocabularies and collections.

Limitations of SKOS for Interoperability

Even if SKOS is considered a useful model for the enhancement of semantic interoperability, it has some shortcomings that could affect its achievement. Some of them are directly related with the essential features of the SKOS model, as underlined by [Antoine 2008]:

- SKOS semantics make assumptions that distinguish what could be regularly inferred from a statement. For example, if *broader* and *narrower* are inverse of each other it can be inferred that *broader* is transitive. However, this assumes some reasoning that in a machine environment doesn't exist.
- Captions could also be considered as preferred labels, and sometimes they can be ambiguous, putting the interoperability at risk.
- SKOS offers some constructs to precise the concept scheme and meet local needs, as for example `broaderPartitive`. However, it could compromise interoperability between vocabularies when networked.

Other aspects referring to representational issues have been pointed out by [Sanchez and Barriocanal, 2006]:

- The representation of a concept scheme as an RDF graph is not, by itself, enough to make it interoperable because the meaning of the terms in the SKOS vocabulary is not formally defined.
- The existence of similar concepts in different schemes suggests the possibility of establishing mapping criteria to foster the interoperability between them.

The authors summarize these two aspects in one: SKOS does not provide strict computational semantics. That is to say, the representation of a concept scheme as an RDF graph cannot be used as the basis for performing automated tasks associated with knowledge represented in the scheme.

To overcome the shortcomings related with SKOS schemes semantic interoperability, the authors propose an approach based in the use of formal representations to provide the SKOS terms with computational semantics and in the use of intermediate upper-ontologies [are large general

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knowledge bases that include definitions of concepts, relations, properties, constraints and instances, as well as reasoning capabilities of these elements]. The proposed extension of SKOS would help avoid ambiguities and enable inter-thesaurus interoperability.

4. SKOS RELEVANT LITERATURE

In this section we present a non exhaustive selection of the existing literature (mainly papers and some presentations) written in English about the Simple Knowledge Organization System initiative and about some of the implementations of this model in actual projects or initiatives, serving as an example of the opportunities and possible uses of SKOS.

The selected papers and presentations are organized in two tables depending on the scope of the documents:

- The first table contains the main papers about the SKOS model, distinguishing between those papers merely introducing or presenting the model and those that reflect about the foundations of the model or about its development and future improvement.
- The second table contains more than 20 papers related to SKOS implementations at various levels and from different points of view. In this way, we have categorized the papers in 3 main groups: papers about the representation and conversion of vocabularies to the SKOS model; papers about the alignment of vocabularies or concept schemes by the means of SKOS; and papers about the implementation or development of applications for the indexing and retrieval of resources with vocabularies in SKOS.

Each table has several columns with some differences in the information collected and synthesized in them, as explained below.

The first table is composed by four columns: *Bibliographic citation*, *Authorship*, *Purpose & abstract* and *Subjects*. In this table, the bibliographic citation includes the title of the article and the author-date citation [See the complete references at the Bibliography section]. The *Authorship* information column tries to distinguish between the papers created by SKOS developers, members of the SWDWG (Semantic Web Development Working Group), or other authors not necessarily related with the development of SKOS. The purpose & abstract explain briefly the scope and intention of each document, while the subject summarizes it in some keywords.

In the case of the second table, five columns have been created: *Bibliographic citation*, *Authorship*, *Relation with SKOS*, *Subjects* and *Vocabularies involved*. The first two have the same content as the previous table. In the third column, Relation with SKOS, we have tried to identify and summarize how SKOS is used in the initiative or implementation described in the paper. The main concepts of the paper in relation with SKOS and semantic interoperability are presented in the *Subjects* column. Also the vocabularies involved in the initiatives described are listed in the last column.

The last three columns of the second table will help to identify the points in common of these initiatives with the HIVE Project, either because the specific problem addressed by the project or the way SKOS is applied is similar than in HIVE, or because the vocabularies used and maybe already translated into SKOS will be also used in HIVE.

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4.1. Introducing SKOS / SKOS application and development

Bibliographic citation	Authorship	Purpose / Abstract	Subjects
1) INTRODUCTION TO SKOS			
Simple Knowledge Organization and the Semantic Web (Miles, 2006a)	Alistair Miles	Short paper introducing SKOS in two main sections a) Scope, Design and Assumptions and b) Application, Context and Status (2005).	• SKOS
SKOS Core: Simple knowledge organization for the Web. (Miles, Matthews, Wilson and Brickley, 2005)	SKOS WG	This paper introduces SKOS Core, an RDF vocabulary for expressing the basic structure and content of concept schemes (thesauri, classification schemes, subject heading lists, taxonomies, terminologies, glossaries and other types of controlled vocabulary). The main purpose of this paper is to provide an initial basis for establishing clear recommendations for the use of SKOS Core and DCMI Metadata Terms in combination.	• SKOS Core
SKOS: A language to describe simple knowledge structures for the web. (Miles, Matthews, Brickley, Wilson and Roggers, 2005)	SKOS WG	Introduction to SKOS, including: Origins and background, SKOS basic usage and SKOS Core advanced usage, SKOS applications and tools, SKOS web services.	• SKOS
SKOS: Simple Knowledge Organization for the Web (Miles and Pérez-Agüera, 2007)	SKOS WG	Introduction of SKOS and description of some alternatives for integrating Semantic Web services based on the Resource Description Framework (RDF) and SKOS into a distributed enterprise architecture.	• SKOS utility
Encoding controlled vocabularies for the Semantic Web using SKOS Core (Cantara 2006)	Kelvin Smith Library, Case Western Reserve University, Cleveland, Ohio	Literature based review that introduces SKOS to digital librarians.	• SKOS
2) DEVELOPMENT AND APPLICATION OF SKOS			
SKOS and the Ontogenesis of Vocabularies (Tennis, 2005)	Joseph T. Tennis, University of British Columbia	The paper suggests extensions to SKOS Core to make explicit where concepts in a knowledge organization system have changed from one version of the system to another.	• SKOS development
SKOS: Requirements for Standardization	SKOS WG	three questions regarding the planned development of SKOS:	• SKOS development

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Bibliographic citation	Authorship	Purpose / Abstract	Subjects
(Miles, 2006b)		<ul style="list-style-type: none"> - what is the fundamental purpose and therefore scope of SKOS? - which key software components depend on SKOS, and how do they interact? - what is the wider technological and social context in which SKOS is likely to be applied and how might this influence design goals? 	<ul style="list-style-type: none"> • SKOS Standardization
Retrieval and the Semantic Web incorporating A Theory of Retrieval Using Structured Vocabularies (Miles, 2006c)	Alistair Miles DISSERTATION	Alistair Miles masters dissertation "Retrieval and the Semantic Web" which incorporates "A Theory of Retrieval Using Structured Vocabularies" It serves as a theoretical basis of the usefulness of SKOS.	<ul style="list-style-type: none"> • Structured Vocabularies • Semantic Web • Information Retrieval
The Notion of the "Concept Instance": Problems in Modeling Concept Change in SKOS (<i>Draft Discussion Paper</i>) (Tennis, Sutton and Hillmann 2006)	National Science Digital Library (NSDL) Metadata Registry Team Work	Issues around the creation of historical snapshots of concept changes and their encoding in SKOS, in the context of the NSDL Metadata Registry.	<ul style="list-style-type: none"> • SKOS • Versioning • Indexing Languages • Registry
Extending the simple knowledge organization system for concept management in vocabulary development applications (Tennis and Sutton 2008)	National Science Digital Library (NSDL) Metadata Registry Team Work	Describe the development of an extension to the Simple Knowledge Organization System (SKOS) to accommodate the needs of vocabulary development applications (VDA), in the context of the NSDL Metadata Registry.	<ul style="list-style-type: none"> • SKOS development • SKOS tools, VDA • SKOS requirements
On practical aspects of enhancing semantic interoperability using SKOS and KOS alignment (Isaac, 2008)	KRR lab, Vrije Universiteit Amsterdam National Library of the Netherlands	This presentation analyzes some issues related to the endangerment or enhancement of interoperability using SKOS. <i>Conclusion</i> >>Despite some issues, SKOS provides a crucial contribution to enhance interoperability of KOSs	<ul style="list-style-type: none"> • SKOS • Vocabulary alignment • Interoperability

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4.2. Applications of SKOS

Bibliographic information (references in Procite, need revision)	Authorship	Relation with SKOS & interoperability	Subjects	Vocabularies involved
1) REPRESENTATION AND CONVERSION OF VOCABULARIES TO SKOS				
A Method for Converting Thesauri to RDF/OWL (Assem et al., 2004)	Vrije Universiteit Amsterdam, Department of Computer Science University of Amsterdam, Social Science Informatics (SWI)	General methodology for the conversion of existing thesauri to an RDF/OWL representation. (Using XSLT)	<ul style="list-style-type: none"> • Representation of thesauri with RDF/OWL • Translation of vocabularies • Thesauri 	<ul style="list-style-type: none"> • MeSH • WordNet
A Method to Convert Thesauri to SKOS (Assem et al., 2006)	Vrije Universiteit Amsterdam, Department of Computer Science CCLRC Rutherford Appleton Laboratory, Business and Information Technology Department	Conversion of thesaurus structure into SKOS structure. (Using Perl scripts)	<ul style="list-style-type: none"> • Representation of vocabularies with SKOS • Translation of vocabularies • Thesauri 	<ul style="list-style-type: none"> • IPSV • GTAA ((dutch acronym for Common Thesaurus for Audiovisual Archives) • MeSH
Development of an ontology in the context of the semantic web: the migration of the traditional documentary thesaurus (Guzmán Luna, Torres Pardo, and López García, 2006)	Universidad Nacional de Colombia, Sede Medellín	Transformation of a thesaurus into an ontology with SKOS	<ul style="list-style-type: none"> • Representation of vocabularies with SKOS • Transformation of vocabularies • Thesauri 	<ul style="list-style-type: none"> • Tesouro del Centro de Naciones Unidas sobre Asentamientos Humanos / Tesouro del Hábitat.
Encoding Library of Congress Subject Headings in SKOS: Authority Control for the Semantic Web (Harper, 2006)	University of Oregon Libraries	This paper describes how to translate LCSH Authority Records from MARC/XML or MADS XML formats into RDF documents, using XSLT stylesheets	<ul style="list-style-type: none"> • Representation of vocabularies with SKOS • Translation of vocabularies • Subject Headings 	<ul style="list-style-type: none"> • Library of Congress Subject Headings
LCSH, SKOS and Linked Data (Summers, et al. 2008)	Library of Congress	This paper describes a technique for converting Library of Congress Subject Headings MARCXML to Simple Knowledge Organization System (SKOS) RDF. Strengths of the SKOS vocabulary	<ul style="list-style-type: none"> • Representation of vocabularies with SKOS • Translation of vocabularies • Subject Headings 	<ul style="list-style-type: none"> • Library of Congress Subject Headings MARCXML

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		are highlighted, as well as possible points for extension, and the integration of other semantic web vocabularies such as Dublin Core. An application for making the vocabulary available as linked-data on the Web is also described.		
Representing National Diet Library Subject Headings (NDLSH) in SKOS and its Graphical Browser (Nagamori and Sugimoto, 2006)	Univ. of Tsukuba (Japan)	This paper describes how to represent NDLSH in SKOS.	<ul style="list-style-type: none"> • Representation of vocabularies with SKOS • Subject Headings • Vocabularies Browsers 	<ul style="list-style-type: none"> • NDLSH (National Diet Library Subject Heading)
Encoding changing country codes in RDF with ISO 3166 and SKOS (Voss, 2007)	Common Library Network (GBV), Germany	This paper shows how authority files can be encoded in RDF with SKOS for the Semantic Web. In particular for encoding the structure, management, and utilization of country codes as defined in ISO 3166.	<ul style="list-style-type: none"> • Representation of vocabularies with SKOS • Country codes 	<ul style="list-style-type: none"> • ISO 3166 (Country codes)
SKOS: a model for metadata representation and interoperability – Dutch Cultural Heritage Institution thesaurus conversion use case (Malaisé, 2007)	CHOICE team (http://www.nwo.nl/CATCH/CHOICE) CATCH program	This paper describes the SKOS model in comparison with the ISO-standard way of representing thesaurus data, and the process (problems and advantages) of conversion of the GTAA thesaurus into SKOS.	<ul style="list-style-type: none"> • Representation of vocabularies with SKOS • Translation of vocabularies • Thesauri • Cultural Heritage 	<ul style="list-style-type: none"> • GTAA thesaurus
Semantic interoperability issues from a case study in archaeology (Tudhope, Binding and May, 2008)	University of Glamorgan, Uk English Heritage	First steps in mapping different (a) datasets and (b) vocabularies to the CIDOC CRM, within an RDF implementation. Discuss issues concerning the mapping of domain thesauri to upper (core) ontologies	<ul style="list-style-type: none"> • Datasets mapping • Representation of vocabularies with SKOS • Thesaurus • Mapping SKOS vocabularies to upper ontologies 	<ul style="list-style-type: none"> • CIDOC CRM • English Heritage National Monuments Record • Centre Thesauri
Subject classification with DITA and SKOS: managing formal subjects (Hennon, Anderson and Bird, 2005)	IBM Corporation	DITA is a personal content management that allows the user the management of the subjects of its resources. DITA topics are classified with subjects that are expressed in SKOS for runtime processing.	<ul style="list-style-type: none"> • Personal content management • Subject management • Tools • Representation of 	

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			vocabularies with SKOS	
2) VOCABULARY ALIGNMENT WITH SKOS				
Making use of upper ontologies to foster interoperability between SKOS concept schemes (Sanchez-Alonso and Garcia-Barriocanal, 2006) Semantic Interoperability Between SKOS Concept Schemes Using Metadata (Sanchez-Alonso and Garcia-Barriocanal, 2005)	University of Alcalá, Spain	The purpose of this research is to introduce a mapping of the Simple Knowledge Organization Systems (SKOS) Core metadata to an ontology-based model, whose main aim is to foster the semantic interoperability of different concept schemes.	<ul style="list-style-type: none"> • Vocabulary alignment • SKOS vocabularies • Ontologies • Semantic interoperability 	<ul style="list-style-type: none"> • OpenCyc (ontology)
Semantic web and vocabularies interoperability: an experiment with illuminations collections (Angjeli and Isaac, 2008)	Antoine Isaac (SKOS DG) and Anila Angjeli (BNF); STITCH (SemánTic Interoperability To access Cultural Heritage) Project (Netherland)	Experiment of semantic interoperability between a controlled vocabulary and a classification system, made on two digital iconographic collections	<ul style="list-style-type: none"> • Vocabulary alignment • Controlled vocabularies • Classification systems • Semantic interoperability • Cultural heritage 	<ul style="list-style-type: none"> • Mandragore (controlled vocabulary) • Iconclass (Classification system)
A SKOS Core approach to implementing an M2M terminology mapping server (Macgregor, Joseph and Nicholson, 2007)	University of Strathclyde, UK	Pilot M2M terminology server employing terminology mapping and using SKOS Core to mark-up terminology responses. Interoperability between terminologies in order to facilitate user access to the discrete heterogeneous digital objects held therein.	<ul style="list-style-type: none"> • Vocabulary alignment • Schema mapping • MPM (machine-to-machine) web service • Retrieval applications 	<ul style="list-style-type: none"> • Dewey Decimal Classification (DDC) • HILT: High-level Thesaurus http://hilt.cdli.strath.ac.uk
Thesaurus and metadata alignment for a semantic e-culture application (Tordai, Omelayenko, and Schreiber, 2007)	VU University, Amsterdam	Methodological approach for porting cultural repositories to the Semantic Web, focusing on the global picture of the required mappings and alignments. It uses SKOS as the thesaurus schema and the method for thesauri conversion proposed by van [Assem, et al. 2006]	<ul style="list-style-type: none"> • Vocabulary conversion • Metadata schema mapping • Metadata value mapping • Vocabulary alignment • Thesaurus; • e-culture; art; image 	<ul style="list-style-type: none"> • Art & Architecture Thesaurus (AAT) • Thesaurus of Geographic Names (TGN) • Dutch ethnographic thesaurus SVCN • VRA metadata schema

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The Mapping Schema from Chinese Agricultural Thesaurus to AGROVOC (Liang et al. 2006)	Food and Agriculture Organization (FAO) of the United Nations	Criteria and the procedures for mapping the Chinese Agricultural Thesaurus (CAT) to FAO's multilingual agricultural thesaurus AGROVOC. It proposes modifications to the interthesaurus mapping rules provided in the Simple Knowledge Organization System (SKOS) specification.	<ul style="list-style-type: none"> • Vocabulary alignment • Mapping Schema • Thesaurus 	<ul style="list-style-type: none"> • Chinese Agricultural Thesaurus • AGROVOC
Tag Interoperability in Cultural Web-based Applications (Carmagnola et al. 2008)	Dipartimento di Informatica, Università di Torino,	This paper presents an approach that shows how user interaction data (tags) generated by one application can be exploited by another one in similar domain for integrating user models in distributed and interactive environments. As a scenario, we discuss the tags interoperability among two adaptive systems into the cultural heritage domain. In the interoperability between iCITY and CHIP, we use an open API to request and link user data, and the API used SKOS.	<ul style="list-style-type: none"> • Vocabulary alignment • Tags mapping • cultural heritage 	<ul style="list-style-type: none"> • CHIP system (Cultural Heritage Information Personal-ization) • iCITY is a social web-based, multi-device recommender system
3) ANNOTATION AND RETRIEVAL APPLICATIONS USING SKOS VOCABULARIES				
Towards Terminology Services: experiences with a pilot web service thesaurus browser (Tudhope and Binding, 2006)	Hypermedia Research Unit, University of Glamorgan Wales, UK	Experiments with a pilot web service demonstrator ('rich client' browser) for the SKOS API protocol; concepts from the GEneral Multilingual Environmental Thesaurus (GEMET).	<ul style="list-style-type: none"> • Environmental Science • SKOS thesaurus • web services • thesaurus browser 	<ul style="list-style-type: none"> • GEneral Multilingual Environmental Thesaurus (GEMET).
Finding Data Resources in a Virtual Observatory Using SKOS Vocabularies (Gray, Gray and Ounis, 2007)	International Virtual Observatory Alliance (http://ivoa.net/)	Matching searches in VOExplorer, against tags provided by the resources using SKOS vocabularies. They are translating these vocabularies into SKOS.	<ul style="list-style-type: none"> • Astronomy • Tags /keywords • retrieval 	<ul style="list-style-type: none"> • Astronomy Outreach Imagery Metadata • The Astronomy Thesaurus • The IVOA Thesaurus • Universal Content Descriptors
Searching for Relevant Video Shots	Retrieval Group of the	Use SKOS concepts to represent subject	<ul style="list-style-type: none"> • Annotations with SKOS 	<ul style="list-style-type: none"> • Library of Congress

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<p>in BBC Rushes Using Semantic Web Techniques (Allen, Petrushin and Roqueiro 2006)</p>	<p>Information Access Division, Information Technology Laboratory (ITL), NIST, U.S. Commerce Department.</p> <p>Bradley P. Allen (Siderean Software); Valery A. Petrushin, Gang Wei (Accenture Technology Labs); Damian Roqueiro (University of Illinois at Chicago)</p>	<p>metadata in a content-based search and navigation systems of BBC rushes. This web-based system helps TV program makers select relevant shots from a repository of shots that were created automatically from rushes.</p>	<ul style="list-style-type: none"> • TV/Broadcast • MPEG7; • Web services 	<p>Thesaurus of Graphical Materials 1 (TGM 1)</p>
<p>SOBOLEO – Social Bookmarking and Lightweight Engineering of Ontologies (Zacharias and Braun, 2007)</p>	<p>Forschungszentrum Informatik, FZI, Germany Mature project</p>	<p>SOBOLEO a system for the webbased collaborative engineering of SKOS ontologies and annotation of web resources</p>	<ul style="list-style-type: none"> • Annotation with SKOS • Social bookmarking; • Web services 	<ul style="list-style-type: none"> • Users tags
<p>Convergence of Web and TV Broadcast Data for Adaptive Content Access and Navigation (Bellekens, et al. 2008)</p>	<p>Technische Universiteit Eindhoven, Netherlands</p>	<p>Semantic Web techniques are applied for enriching and aligning Web data and (live) broadcast content. The resulting RDF/OWL knowledge structure is the basis for iFanzys main functionality, like semantic search of the broadcast content and execution of context-sensitive recommendations.</p>	<ul style="list-style-type: none"> • Data Alignment • TV/Broadcast vocabularies 	<ul style="list-style-type: none"> • TV genre vocabularies: <ul style="list-style-type: none"> ○ TV-Anytime Genres, ○ XMLTV Genres ○ IMDB Genres
<p>Information Integration from Heterogeneous Data Sources: a Semantic Web Approach. (Kunapareddy, et al. 2006)</p>	<p>Center for Biosecurity and Public Health Informatics Research, Houston, TX</p>	<p>An integrated RDF repository has been built from data submitted by eight community hospitals. For each data source, a conceptual graph is created according to the SKOS framework. Uses XML structure of incoming data and a reference ontology to automatically derive a conceptual graph representing the semantics of the data. This graph, which they call a “Simple Concept Organization System” (SCOS), is mapped (semi-utomatically) to a set of integration ontologies for semantic</p>	<ul style="list-style-type: none"> • Automatic generation of SKOS vocabularies • Health data • Data Integration 	<ul style="list-style-type: none"> • Adapted from data sources

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		integration.		
4) ONTOLOGY MAPPING				
Ontology mappings to improve learning resource search (Gasevic and Hatala, 2006)	School of Interactive Arts and Technology, Simon Fraser University	Interoperate e-learning systems based on different ontologies Searching for learning resources using multiple ontologies; mapping between ontologies (course ontology and ACM CCS classification system), represented in SKOS /// Ontology mapping algorithms for repository searching	<ul style="list-style-type: none"> • Ontology mapping • Mapping algorithms • e-learning resources • learning object repositories; 	<ul style="list-style-type: none"> • ACM CCS
DSSim—managing uncertainty on the semantic web (Nagy, Vargas-Vera and Motta, 2007)	Knowledge Media Institute (Kmi) The Open University; Department of Information Systems, Poznan University of Economics (Poland)	This is less related with SKOS and more with ontologies, but could be an example of this kind of papers (there is more in the same workshop) . [<i>International Workshop on Ontology Matching</i>] Mapping ontologies, some of them in SKOS, creating a SKOS Parser: This parser convert SKOS file to OWL which is then processed using the alignment API. Additionally we have developed a chunk SKOS parser which can process SKOS file iteratively in chunks avoiding memory problems.	<ul style="list-style-type: none"> • Ontology mapping • Mapping algorithms 	

5. SKOS RELATED INITIATIVES

In this section we have drawn a panorama of the several initiatives related to SKOS in various aspects, some of them presented in the papers gathered in the previous section and others already collected in the SKOS official webpage and development wiki.

These initiatives have been synthesized in four areas, namely: a list of specific projects and particular implementations of SKOS; a list of tools and applications compliant with the SKOS model, classified in terms of the task that they support in the vocabulary workflow; a compilation of SKOS data in the sense of vocabularies expressed in the SKOS model and openly available online; and finally, a selection of the main research institutions and groups that contribute to the development of SKOS, consolidating and widening its scope.

5.1. Projects and Implementations of SKOS

In this section, around 20 projects applying SKOS for different purposes have been gathered. The scope and purposes of these initiatives vary in a wide range, with regard to the features, levels of implementation and potential uses of SKOS that they adopt.

Some of the projects use Simple SKOS for the representation of vocabularies, as do the *CrisCross* Project developing a multilingual thesaurus-based research vocabulary; the *Bio-zen ontology* framework, representing life science vocabularies; the *NewsML G2 initiative*, translating the IPTC codes into SKOS; or *BC2* with the proposal of an SKOS representation of the BLISS general faceted classification.

Two more projects have translated vocabularies into SKOS for experimental purposes, providing visualization and search of these vocabularies, as *LCSH.info* or the *Hybrid And Network-Assisted Vocabulary Interface (HANAVI)* graphical browsers. There are also other projects that have developed specific applications for the creation and registration of SKOS vocabularies, as the *NSDL Vocabularies Registry*, that allows the automatic generation of a RDF graph of the concept schemes registered.

Besides the vocabulary representation, other projects go further and focus in the development of indexing and retrieval systems based on or enhanced by the use of SKOS. Some examples are: the BIRN Project with *BIRNlex*, a lexicon for neurosciences expressing lexical with SKOS, and allowing the data annotation, integration and query; the *CHOICE Project*, developing a web service matching query terms to SKOS thesaurus concepts; and even *Squiggle*, an application framework for model-driven development of real-world Semantic Search Engines.

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Finally, we have gathered some initiatives working in the mapping of vocabularies using SKOS features, also enabling the semantic search across different collections and vocabularies. For example, the *AIMS Project* of the FAO, with a semantic search service that makes use of mapped agriculture thesauri; the *High-level Thesaurus (HILT)*, searching application in multiple vocabularies and systems based on a M2M terminology server; the semantic interoperability initiative of learning object repositories in *LORNET*; the *MultimediaN N9C E-Culture project* and the *STITCH (SemánTic Interoperability To access Cultural Heritage) Project*, both supporting semantic search through several cultural heritage vocabularies and collections.

The projects are listed alphabetically and presented in a four columns table with basic data: project name and URL, authors or institutions involved in the project, relation with SKOS and vocabularies used in the project.

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Project name and URL	Authors /groups /institutions involved	Relation with SKOS & interoperability	Vocabularies involved...
AIMS project http://www.fao.org/aims	Food and Agriculture Organization (FAO) of the United Nations	Semantic search service that makes use of mapped agriculture thesauri. Agrovoc has been converted into SKOS and is being mapped to two other vocabularies: the Chinese Agricultural Thesaurus (CAT) and the National Agricultural Library thesaurus (NAL). This mapping uses links inspired by the SKOS mapping vocabulary.	<ul style="list-style-type: none"> • Agrovoc Thesaurus • Agris/Caris Classification Scheme (ASC) • FAO Technical Knowledge Classification Scheme (TKCS) • FAOTERM vocabulary
Bio-zen ontology framework http://neuroscientific.net/index.php?id=43	Semantic Synapse Project in Neuroscientific.org Matthias Samwald, Semantic Web Company, Austria	Bio-zen attempt to represent data, information and knowledge from research in all facets of the life sciences on the Semantic Web. SKOS is used in bio-zen for the representation of many existing life sciences vocabularies, taxonomies and ontologies coming from the "Open Biomedical Ontologies" (OBO) collection http://www.fruitfly.org/~cjm/obo-download/	<ul style="list-style-type: none"> • Open Biomedical Ontologies (OBO)
BIRNLex: a lexicon for neurosciences https://xwiki.nbirn.net/xwiki/bin/view/BIRN-OTF/+BIRNLex+Nuts+And+Bolts	Biomedical Informatics Research Network, Ontology Task Force	BIRNLex is an integrated ontology+lexicon used for various purposes within the BIRN Project to support semantically-formal data annotation, semantic data integration, and semantically-driven, federated query resolution. The goal is to use SKOS for all lexical qualities.	<ul style="list-style-type: none"> • Neuronames • Brainmap.org classification schemes • RadLex • Gene Ontology • Reactome • OBI (Ontology of Biomedical Investigation) • PATO (Phenotype and Trait Ontology) • Subcellular Anatomy Ontology (CCDB - http://ccdb.ucsd.edu/) • MeSH
CHOICE@CATCH Project http://ems01.mpi.nl/choice-wiki/CHOICE_Main_Page	Nederlands Instituut voor Beeld en Geluid, CATCH program of the NWO (Netherlands)	Aim: develop key technology to ensure continuous access to the cultural riches of the world Dutch Cultural Heritage Institution thesaurus conversion to SKOS. Developed a web service that uses a Sesame RDF	<ul style="list-style-type: none"> • Dutch Cultural Heritage Institution thesaurus

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		web repository containing the SKOS version of the GTAA thesaurus to retrieve the 'term contexts' of the terms in the input list.	
CrissCross http://www.fbi.fh-koeln.de/institut/projekte/CrissCross/index_en.html	The German National Library Cologne University of Applied Sciences	The goal of the CrissCross project is the creation of a multilingual, user-friendly, thesaurus-based research vocabulary. To this end, the subject headings of the Subject Heading Authority Files (SWD) are linked with the notations of the Dewey Decimal Classification (DDC).	<ul style="list-style-type: none"> • Subject Heading Authority Files (SWD) • Dewey Decimal Classification (DDC).
FACET Project http://www.comp.glam.ac.uk/pages/research/hypermedia/Facet/index.htm	Hypermedia Research Unit (Semantic Knowledge Organisation Systems) University of Glamorgan, UK	Investigating the potential of semantic expansion in retrieval. It aimed to take advantage of facet structure in both the interface and retrieval mechanism. They have developed some lightweight and flexible XML formats for the purposes of representing and storing thesaurus data for various research projects. As part of this work, they have experimented with XPATH querying techniques, and done some initial experiments with the Simple Knowledge Organisation System (SKOS) RDF format.	<ul style="list-style-type: none"> • Getty Art & Architecture Thesaurus • Alexandria Digital Library Feature Type Thesaurus (FTT)
General faceted classification, "BC2" http://www.blissclassification.org.uk	Bliss Classification Association (BCA)	Classifications in SKOS (only proposal)	<ul style="list-style-type: none"> • General faceted classification, "BC2"
HANA VI: Hybrid And Network-Assisted Vocabulary Interface http://raus.slis.tsukuba.ac.jp/subjects/graph	University of Tsukuba, Japan	Representation of vocabularies with SKOS Graphical Browser	<ul style="list-style-type: none"> • National Diet Library Subject Headings (<i>NDLSH</i>)
HILT: High-level Thesaurus: http://hilt.cdrl.strath.ac.uk/	Centre for Digital Library Research (CDLR), University of Strathclyde	Searching application in multiple vocabularies and systems. Development of an M2M terminology mapping server, to enable improved cross-repository searching. Use SKOS-Core as the 'mark-up' for sending out terminology sets and classification data responses	<ul style="list-style-type: none"> • Art & Architecture Thesaurus (AAT) • CAB Thesaurus, CABI • Dewey Decimal Classification (DDC) • Global Change Master Directory (GCMD) (Science Keywords), NASA • HASSET Thesaurus, UK Data Archive at the University of Essex • Integrated Public Sector Vocabulary (IPSV), e-Government Unit (UK) • Joint Academic Coding System (JACS)

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			<ul style="list-style-type: none"> • JITA Classification Schema, E-Prints in Library and Information Science (E-LIS) • Library of Congress Subject Headings (LCSH) • Medical Subject Headings (MeSH) • National Monuments Record Thesaurus (NMR), English Heritage • UNESCO Thesaurus • Wordnet
IVOA Semantics Working Group http://www.ivoa.net/Documents/latest/Vocabularies.html	IVOA (International Virtual Observatory Alliance)	Use of SKOS vocabularies to facility Access and retrieval of resources in the IVOA	<ul style="list-style-type: none"> • Astronomy Outreach Imagery Metadata • The Astronomy Thesaurus • The IVOA Thesaurus • Universal Content Descriptors
KoMoHe project "Competence Center Modeling and Treatment of Semantic Heterogeneity" http://www.gesis.org/en/research/programs-and-projects/information-science/project-overview/komohe/	GESIS / Social Science Information Centre (IZ), Germany -	<p>KoMoHe supervised a terminology mapping effort, in which 'cross-concordances' between major controlled vocabularies were organized, created and managed.</p> <p>They plan on transferring the cross-concordance data to the SKOS format.</p> <p>(only proposal)</p>	
Library of Congress Subject Headings [Linked data] http://lcsb.info	Library of Congress	An experimental service that makes the Library of Congress Subject Headings available as linked-data using the SKOS vocabulary.	<p>Encoding Library of Congress Subject Headings in SKOS: Authority Control for the Semantic Web.</p> <p>(Harper, 2006)</p> <p>LCSH, SKOS and Linked Data</p> <p>(Summers, et al. 2008)</p>
LORNET , Theme 1 Interoperability of learning object repositories http://www.lornet.org/Lornet/Leprojetderecherche/Theme1/tabid/276/language/en-US/Default.aspx	LORNET, Simon Fraser University, Canada	Ontology mapping algorithms with SKOS for repository/digital library searching, related to learning resources in a specific course.	<ul style="list-style-type: none"> • ACM CSS
MichaelPlus Project http://www.michael-culture.org/	Ministry of Culture of the CR, Department of Movable Cultural	<p>The Michael platform supports interoperability in the schema, record and repository levels.</p> <p>They plan to achieve the semantic level with SKOS.</p>	

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	Heritage Preservation, Museum and Galleries	(only proposal)	
MultimediaN N9C E-Culture project http://e-culture.multimedian.nl/	University of Vrije University of Amsterdam CWI (Centrum voor Wiskunde en Informatica) (all Netherlands)	Aim: to create a large virtual collection of cultural-heritage objects that supports semantic search. Demonstrator where multiple collections and vocabularies are converted to RDF/OWL and are aligned semantically. Translation of some vocabularies into SKOS.	<ul style="list-style-type: none"> • Art & Architecture Thesaurus (AAT) • Thesaurus of Geographic Names (TGN) • Dutch ethnographic thesaurus SVCN
NewsML G2 and the Semantic Web http://newsml.cwi.nl/	K-Space (EU) CWI (Centrum voor Wiskunde en Informatica) (Netherlands) The Agence France Presse (AFP)	IPTC maintains a number of controlled vocabularies, called Newscodes, that have been translated into SKOS. Demo of NewsML	<ul style="list-style-type: none"> • IPTC News Codes
NSDL Vocabularies http://wiki.metadataregistry.org/NSDL_Registry	University of Washington; University of Cornell NSDL (National Science Digital Library)	Registry of vocabularies / concept schemes that allows the automatic generation of SKOS RDF graphs.	A Metadata Registry from Vocabularies Up: The NSDL Registry Project (Hillmann, et al 2007)
Semantic Web Model for Information Integration http://www.phinformatics.org/ResearchProjects/InformationIntegration/tabid/79/Default.aspx	Center for Biosecurity and Public Health Informatics Research (CBPHIR) at the UT Health Science Center, Houston, School of Health Information Sciences	Automatic generation of SKOS conceptual graphs, using the XML structure of incoming data and a reference ontology. The graphs o “Simple Concept Organization System” (SCOS), are mapped (semi-utomatically) to a set of integration ontologies for semantic integration	
SKOSsaurus Project http://web.archive.org/web/20070102065709/http://skosaurus.rrecktek.com/ [Non continued project]	Ken Sall and Ronald P. Reck .	Pilot implementation using RDF-based SKOS (Simple Knowledge Organization System) to represent federal glossaries and acronym lists. The thesaurus approach enables term gatherers and authors to input terms and definitions via Excel, via a web form, or by using RDF editors.	
STITCH (SemánTic Interoperability To access Cultural Heritage) Project (Netherland) DEMONSTRATOR: http://www.cs.vu.nl/STITCH/BNF_KB_demo.html	Bibliothèque nationale de France National Library of the Netherlands	Vocabulary alignment with SKOS Semantic interoperability, especially in relation to conduct semantic searches across several digital heritage collections.	<ul style="list-style-type: none"> • Mandragore ; (controlled vocabulary) • Iconclass (Classification system)
Squiggle: an application framework for model-	CEFRIEL (Center of	Squiggle is a framework to support the development	<ul style="list-style-type: none"> • Music ontology

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<p>driven development of real-world Semantic Search Engines http://squiggle.cefriel.it/</p>	<p>Excellence For Research, Innovation, Education and industrial labs) Polytechnic University of Milan, Italy</p>	<p>of domain-specific search engines that exploit the semantics of domain ontologies to improve the search functionalities. It supports both the conceptual indexing phase and the semantic search. For the Semantic Suggestions, Squiggle exploit some SKOS primitives.</p>	<ul style="list-style-type: none"> • Ski Ontology
<p>SWED (Semantic Web Environmental Directory) http://www.swed.org.uk</p>	<p>Semantic Web Advanced Development - Europe (SWAD-E) Project, EU</p>	<p>Web-based directory of organisations and projects in the United Kingdom. 5 distinct controlled vocabularies used within the SWED system, and are represented in RDF. http://www.swed.org.uk/swed/swed technical resources.htm</p>	
<p>Terminology Services Project http://www.oclc.org/research/projects/termservices/</p>	<p>OCLC Online Computer Library Center, Inc.</p>	<p>Provides Web-based services for controlled vocabularies. Retrieve concepts/headings in multiple representations including HTML, MARC XML, SKOS, and Zthes.</p>	<ul style="list-style-type: none"> • Faceted Application of Subject Terminology (FAST subject headings) • Form and genre headings for fiction and drama • Library of Congress AC Subject Headings • Library of Congress Subject Headings • Medical Subject Headings (MeSH®) • Thesaurus for graphic materials: TGM I, Subject terms • Thesaurus for graphic materials: TGM II, Genre terms

5.2. Tools

There exist many different SKOS compliant tools that have been gathered for this section. The relation of these tools with SKOS covers a wide range, from tools strongly related to SKOS or created within the specification, as in the case of the SKOS Validator or the SKOS API, to some software components that simply offer an extension to a particular tool, adding some functionalities for the representation or automatic generation of vocabularies in SKOS.

SKOS is intended to support the interoperation of three principal software components involved in the management of digital libraries: (a) a tool to manage the development of a controlled structured vocabulary; (b) a tool to manage the development of a subject index or classification for a particular collection of items; (c) a tool to enable retrieval of items from a collection using a vocabulary and an index.

This software components configure the software architecture anticipated by [Miles, 2006], when designing the workflow of vocabularies creation and use. In this workflow, three types of applications can be distinguished: the “[Vocabulary Development Application](#)” (VDA), the “[Indexing Application](#)” (IA) and the “[Retrieval Application](#)”.

The tools presented in the table below, as far as possible, have been organized and classified according to these three categories:

- In the first group, of [Vocabulary Development Applications](#) and other tools useful for this task, we have put together the SKOS Validator; the thesaurus creation tools *Tematres* and *ThManager* with SKOS export capabilities; *Synaptica*, the KOS management commercial tool from Dow Jones - Factiva; and SKOS conversion tools like *SKOS2GenTax*, *Annocultor*, *gettyconvert* and those of the University of Vrije (Amsterdam). Also fall into this category the plugins for some other tools as the *Protégé* ontologies editor, *Flickr* and *Wordpress*, which allow the generation of SKOS RDF graphs.
- The second group presents some [Indexing Applications](#) or related tools, like the *KEA keyphrase extraction algorithm* for the indexing of resources with SKOS vocabularies; a content authoring tool that uses SKOS for subject encoding; an *add-on to DSpace* repositories allowing the subject indexing of resources browsing and selecting terms from a SKOS vocabulary; and finally *SOBOLEO*, that allows the annotation of resources developing collaborative vocabularies in SKOS at the same time.
- The third group presents some specific [Retrieval Applications](#) that provide access to thesauri and other simple knowledge organisation systems and enable the query of concept in these vocabularies, as the *SKOS API*, or the *XPATH* and *FACET* web interfaces of the Hypermedia Research Unit of the University of Glamorgan.

In this case we have used a five column table, with the following basic data: tool name and URL, authors or institutions involved in its development, the specific kind of tool, its relation with SKOS

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and interoperability, and if available, the vocabularies involved in the project or presented as an example of the tool usefulness.

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Tool name and URL	Authors /groups /institutions involved	Kind of Tool	Relation with SKOS & interoperability	Vocabularies involved
1) Vocabulary Development Applications and other tools useful for this task				
SKOS Validator http://esw.w3.org/topic/SkosValidator	Alistair Miles	SKOS RDF validator	RDF syntax checking and RDF schema validation.	
Tematres http://www.r020.com.ar/tematres/index.en.html	Diego Ferreyra	GPL thesaurus authoring tool	SKOS as an output format	
ThManager http://thmanager.sourceforge.net/	Advanced Information Systems Laboratory of the University of Zaragoza, Spain	SKOS vocabulary creator (also mapping, as vocabularies can be imported)	Creating and visualizing SKOS RDF vocabularies	Examples: <ul style="list-style-type: none"> • GEMET (General Multilingual European Thesaurus) • AGROVOC • UNESCO Thesaurus European Territorial Units • ISO-639
Vrije Un. Thesaurus conversion tools http://thesauri.cs.vu.nl/eswc06/	University of Vrije	Conversion tool	Convert thesaurus to SKOS 3 conversion programs (each thesaurus) in Perl.	<ul style="list-style-type: none"> • IPSV • GTAA • MeSH
SKOS2GenTax http://www.heppnetz.de/projects/skos2gentax/	Semantics in Business Information Systems Group (SEBIS), University of Innsbruck, Austria.	Conversion tool	Converts hierarchical classifications available in the W3C SKOS format into RDF-S or OWL ontologies	
AnnoCultor (http://annocultor.sourceforge.net/)	eCulture Project (http://e-culture.multimedien.nl)	Mapping tool	Create SKOS representation of existing vocabularies	
Synaptica 6.4 http://factiva.com/investigative/releases/20070605_synaptica.asp?node=menuElem1176	Dow Jones Factiva	Knowledge Management System	Semantic Web-enabled knowledge organization system for the enterprise, collaborate and create structured vocabularies including taxonomies, thesauri and ontologies. Supports RDF SKOS and OWL.	
Gettyconvert http://e-	MultimediaN N9C E-Culture project	Conversion tool	Scripts in perl for the conversion of Getty vocabularies (AAT, TGN	<ul style="list-style-type: none"> • Art & Architecture Thesaurus (AAT)

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culture.multimedien.nl/software/gettyconvert/			and ULAN) XML files into SKOS.	<ul style="list-style-type: none"> • Thesaurus of Geographic Names (TGN) • Union List of Artist Names (ULAN)
PLUGINS				
SKOS Editor Protégé plugin (http://code.google.com/p/skoseditor/)	EU Sealife project (http://www.biotec.tu-dresden.de/sealife/) and CO-ODE (http://www.co-ode.org/)	Plugin for Protégé (thesauri creation tool)	support for viewing and editing SKOS vocabularies	
Net Flickr Backup (http://search.cpan.org/~ascope/Net-Flickr-Backup)	Aaron Straup Cope (Yahoo!)	Plugin - Backup tool for Flickr	Flickr account with all comments, tags, annotations in RDF and using SKOS for concepts	
Open Link Data Spaces (http://esw.w3.org/topic/OpenLinkDataSpaces)	Open Link Software http://www.openlinksw.com/	Plugin for export - Distributed Collaborative Application platform	Creates RDF graphs (including SKOS information) about each ODS account activity	
Morten's FOAF/SKOS plugin for WordPress (http://www.wasab.dk/morten/blog/archives/2004/09/01/skos-output-from-wordpress)	Dan Brickley	exporting Wordpress categories	SKOS in RDF/N3 as an output format (Dan Brickley script)	
2) Indexing Applications				
KEA -The keyphrase extraction algorithm http://www.nzdl.org/Kea	Waikato University, New Zealand	Indexing Application	indexing documents with terms from any thesaurus or vocabulary in SKOS format	<ul style="list-style-type: none"> • <u>Agrovoc</u> thesaurus; • <u>Mesh terms</u>
Darwin Information Typing Architecture (DITA XML) http://www.ibm.com/developerworks/xml/library/x-dita10/	IBM	Content authoring tool	Content authoring tool that allows the management and classification of subjects in personal content in SKOS	
SOBOLEO – Social Bookmarking and Lightweight Engineering of Ontologies (http://mature-ip.eu/en/tools)	Forschungszentrum Informatik, FZI, Germany MATURE Project	Annotation tool / SKOS ontology creation tool VDA/ IA /RA	SOBOLEO a system for the webbased collaborative engineering of SKOS ontologies and annotation of web resources. SOBOLEO is a Web application	SOBOLEO – Social Bookmarking and Lightweight Engineering of Ontologies (Zacharias and Braun, 2007)

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			developed using the Google Web Toolkit; it runs on an Apache Tomcat server. Its ontology formalism is based on SKOS.	
Ontology Add-on http://dspace-dev.dsi.uminho.pt:8080/en/addon_ontology.jsp	Universidade do Minho (Portugal)	Add-on for DSpace /IA and RA	The ontology add-on allows the user to choose from a defined set of keywords organised in an ontology tree and then use these keywords to describe items while they are being submitted	<ul style="list-style-type: none"> • ACM Computing Classification System [1998 version]
• Retrieval Applications				
SKOS API http://www.w3.org/2001/sw/Europe/reports/thes/skosapi.html	Dave Beckett, Nikki Rogers, Alistair Miles	Retrieval Application	Provide access to thesauri and other simple knowledge organisation systems (SKOS) via the web (JAVA)	
XPATH search and navigation on SKOS format files http://www.comp.glam.ac.uk/~facet/formats/skos/skos_search.htm	Hypermedia Research Unit, University of Glamorgan, Pontypridd, Wales UK	Query tool	XPATH expressions to query a thesaurus directly from a SKOS format RDF file	<ul style="list-style-type: none"> • Alexandria Digital Library Feature Type Thesaurus • Government Category List • Australian Public Affairs Information Service • Guidelines on Subject Access to Individual Works of Fiction, Drama etc.
The FACET web interface Demonstrations (SKOS API protocol) http://www.comp.glam.ac.uk/~FACET/webdemo/default.htm	Hypermedia Research Unit, University of Glamorgan Wales, UK	Retrieval Application	Dynamically generated, data driven "query builder" web interface	<ul style="list-style-type: none"> • Getty Art & Architecture Thesaurus (AAT)
ClioPatria semantic search web-server http://e-culture.multimedien.nl/software/ClioPatria.shtml	MultimediaN N9C E-Culture project	Retrieval Application	SWI-Prolog based platform for Semantic Web Applications. Used in MultimediaN N9C E-Culture project; DBtune project, CATCH CHIP project and NewsML G2 K-Space project	

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5.3. SKOS Data

Several SKOS vocabularies freely available online have been gathered for this section. The table, ordered alphabetically by the name of the vocabulary, includes the authors of the vocabulary translation or generation and the links to the RDF graphs or the webpage that contain the URL of the graphs or information about the translated vocabulary.

SKOS data initiative and URL	Author	Vocabularies
ACM CCS in SKOS http://dspace-dev.dsi.uminho.pt:8080/en/addon_acmccs98.jsp	Universidade do Minho (Portugal)	ACM Computing Classification System [1998 Version]
RDF Description of AGROVOC [broken link]	Food and Agriculture Organization (FAO)	AGROVOC FAO Agricultural Thesaurus
RDF description of the FTT (2002-07-03 release) http://www.comp.glam.ac.uk/~facet/formats/skos/skos_FTT.rdf	Ceri Binding, University of Glamorgan	Alexandria Digital Library Feature Type Thesaurus
RDF Description of the APAIS thesaurus http://isegserv.itd.rl.ac.uk/skos/apais/	Alistair Miles	APAIS (Australian Public Affairs Information Service) Thesaurus
RDF description of the GCL http://isegserv.itd.rl.ac.uk/skos/gcl/	Alistair Miles	GCL UK Government Category List
RDF Description of the GEMET http://isegserv.itd.rl.ac.uk/skos/gemet/	Alistair Miles	GEMET General Multilingual Environmental Thesaurus
IANA Language Subtag Registry in SKOS http://esw.w3.org/topic/IANA_Language_Subtag_Registry_in_SKOS	Jakob Voss	IANA Language
IAU/IVOA Thesauri http://www.astro.physik.uni-goettingen.de/~hessman/rdf/index.html	IVOA (International Virtual Observatory Alliance)	<ul style="list-style-type: none"> • IAU93 • IVOAT (IVOA Thesaurus) • UCD1 • Sky • math
Musicbrainz http://www.ivan-herman.net/Misc/2007/Mu.rdf#	Ivan Herman	Instrument taxonomy
Vrije Universiteit converted thesaurus http://thesauri.cs.vu.nl/eswc06/	Vrije UNiversiteit	<ul style="list-style-type: none"> • IPSV • GTAA • MeSH
ISO 3166 RDF Representation http://downlode.org/Code/RDF/ISO-3166/countries	Earle Martin	ISO 3166 definitions of country names.
ISO 639 RDF Representation http://downlode.org/Code/RDF/ISO-639/languages	Earle Martin	ISO 639 definition of language names
Library of Congress Subject Headings http://lcs.info	Library of Congress	Library of Congress Subject Headings (http://lcs.info/static/lcsh.nt.zip)
RDF description of the UKAT http://isegserv.itd.rl.ac.uk/skos/ukat/	Alistair Miles	UKAT UK Archival Thesaurus
SKOS Version of WordNet 2.0 http://isegserv.itd.rl.ac.uk/skos/WordNet.zip	John M. Linebarger	Wordnet

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5.4. Organizations

Concluding this section of SKOS related initiatives, a selection of the main research institutions and groups that contribute to the development of SKOS, consolidating and widening its scope, is presented. Most of them have been already gathered in the SKOSDev [Relevant Organizations](#) section, but here he add some value to that list linking each organization with the specific projects, tools or SKOS data developed by them.

To the data is presented in a four column table: one for the organization name and URL of its webpage if available, and three more for the projects, tools and SKOS data in which these organizations or individuals have been involved. We provide minimal information of the initiatives referred in these three columns as it has been already given in the previous sections.

Organizations	Projects	Tools	SKOS Data
A) Academic Organisations			
Centre for Digital Library Research (CDLR), Department of Computer & Information Sciences, University of Strathclyde, UK http://cdlr.strath.ac.uk/	<ul style="list-style-type: none"> HILT: High-level Thesaurus 	<ul style="list-style-type: none"> HILT SOAP client Demo of SRU HILT2 Emulation Vocabulary Browse/Search Lucene Spell Checker Wordnet BUBL Search (example of embedding toolkit elements in a service) 	
Documentation Research & Training Centre (DRTC), Indian Statistical Institute (ISI), India - http://drtc.isibang.ac.in		<ul style="list-style-type: none"> AGROVOC Thesaurus Plugin for DSpace [Not included in tools, link not found] 	
Hypermedia Research Unit (Semantic Knowledge Organisation Systems) University of Glamorgan, UK http://www.comp.glam.ac.uk/pages/research/hypermedia/	<ul style="list-style-type: none"> EPSRC FACET Project 	<ul style="list-style-type: none"> XPATH search and navigation on SKOS SKOS API Browsing Client 	<ul style="list-style-type: none"> RDF description of the FTT (Alexandria Digital Library Feature Type Thesaurus)
Knowledge Representation and Reasoning Group, Vrije Universiteit Amsterdam, The Netherlands - http://www.cs.vu.nl/en/sec/ai/kr/	<ul style="list-style-type: none"> MultimediaN N9C E-Culture project STITCH 	<ul style="list-style-type: none"> Vrije Un. Thesaurus conversion tools 	<ul style="list-style-type: none"> IPSV GTAA MeSH
HCS Laboratory, University of Amsterdam http://hcs.science.uva.nl/	<ul style="list-style-type: none"> MultimediaN N9C E-Culture project 		
Cologne University of Applied Sciences (Fachhochschule Köln), Germany	<ul style="list-style-type: none"> CrissCross 		

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http://www.fbi.fh-koeln.de/institut/projekte/projekte.htm			
University of Library and Information Science, Tsukuba Science City, Japan. http://www.slis.tsukuba.ac.jp/	<ul style="list-style-type: none"> • HANAVI: Hybrid And Network-Assisted Vocabulary Interface 		
School of Interactive Arts+Technology, Simon Fraser University, Canada http://www.siat.sfu.ca/research/projects/29/	<ul style="list-style-type: none"> • LORNET , Theme 1 Interoperability of learning object repositories 		
Advanced Information Systems Laboratory of the University of Zaragoza, Spain http://iaaa.cps.unizar.es/investigacion/proyectosID_english.html		<ul style="list-style-type: none"> • ThManager 	
Semantics in Business Information Systems Group (SEBIS), (Martin Hepp and Andreas Radinger) University of Innsbruck, Austria. http://sebis.deri.org/		<ul style="list-style-type: none"> • SKOS2GenTax 	
Digital Libraries and Machine Learning Labs, Computer Science Department Waikato University, New Zealand http://www.cs.waikato.ac.nz/		<ul style="list-style-type: none"> • KEA -The keyphrase extraction algorithm 	
Universidade do Minho (Portugal) http://dspace-dev.dsi.uminho.pt:8080/en/welcome.jsp		<ul style="list-style-type: none"> • Ontology Add-on 	<ul style="list-style-type: none"> • ACM CCS in SKOS
B) Government and Other Public Organisations			
Food and Agriculture Organization (FAO) of the United Nations http://www.fao.org/aims/index.jsp	<ul style="list-style-type: none"> • AIMS project 		<ul style="list-style-type: none"> • RDF Description of AGROVOC
German National Library, Information Technology, Germany - http://www.d-nb.de/eng/	<ul style="list-style-type: none"> • CrissCross 		
Dutch National Library (Koninklijke Bibliotheek), The Netherlands - http://www.kb.nl/	<ul style="list-style-type: none"> • STITCH 		
Nederlands Instituut voor Beeld en Geluid / Netherlands Institute for Sound and Vision http://instituut.beeldengeluid.nl/index.aspx?ChapterID=8532	<ul style="list-style-type: none"> • CHOICE@CATCH Project 		

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GESIS / Social Science Information Centre (IZ), Germany - http://www.gesis.org/	<ul style="list-style-type: none"> • KoMoHe Project 		
IVOA Semantics Working Group http://www.ivoa.net/cgi-bin/twiki/bin/view/IVOA/lvoaSematics			<ul style="list-style-type: none"> • IAU/IVOA Thesauri
Library of Congress [Ed Summers]	<ul style="list-style-type: none"> • LCSH.info [Library of Congress Subject Headings in SKOS] 		
Ministry of Culture of the Czech Republic, Department of Movable Cultural Heritage Preservation, Museum and Galleries	<ul style="list-style-type: none"> • MichaelPlus Project 		
CWI (Centrum voor Wiskunde en Informatica), Netherlands	<ul style="list-style-type: none"> • Multimediana N9C E-Culture project • NewsML G2 and the Semantic Web 	<ul style="list-style-type: none"> • AnnoCultor 	
Center for Biosecurity and Public Health Informatics Research (CBPHIR) at the UT Health Science Center, Houston, School of Health http://www.phinformatics.org/	<ul style="list-style-type: none"> • Semantic Web Model for Information Integration 		
Bibliothèque nationale de France (National Library of France)	<ul style="list-style-type: none"> • STITCH (http://www.cs.vu.nl/STITCH/BNF_KB_demo.html#Credit) 		
(Koninklijke Bibliotheek) National Library of the Netherlands	<ul style="list-style-type: none"> • STITCH 		
C) Charities, NGOs and Other Not-For-Profit Organisations			
Council for the Central Laboratory of the Research Councils (CCLRC)	<ul style="list-style-type: none"> • SWAD-Europe 		
OCLC Online Computer Library Center, Inc.	<ul style="list-style-type: none"> • Terminology Service Project 		
CEFRIEL - Politecnico of Milano; Semantic Web group Web site: http://swa.cefriel.it	<ul style="list-style-type: none"> • Squiggle 	<ul style="list-style-type: none"> • Squiggle 	
Verbundzentrale des GBV (VZG) - Common Library Network - Germany - http://www.gbv.de	<i>[See Jakob Voss in Individuals]</i>		
Forschungszentrum Informatik, FZI, Germany (Research Center for Information Technology) http://www.fzi.de/eng/index.php		<ul style="list-style-type: none"> • SOBOLEO [As part of the MATURE Project] 	
D) Commercial Organisations			

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GridLine BV - http://www.gridline.nl		• GridWalker Thesaurus Tools, interested in conversion to SKOS	
Factiva, a Dow Jones & Reuters Company - http://www.factiva.com		• Synaptica 6.4	
RRecktek LLC- http://iama.rrecktek.com	• SKOSaurus Project		
The Agence France Presse (AFP)	• NewsML G2 and the Semantic Web		
Open Link Software http://www.openlinksw.com/		• Open Link Data Spaces	
IBM Corporation		• Darwin Information Typing Architecture (DITA XML)	
E) Individuals			
Aaron Straup Cope http://www.aaronland.net/		• Net Flickr Backup	
Alistair Miles [SWDWG] http://www.bitd.clrc.ac.uk/Person/A.J.Miles		• SKOS API • SKOS Validator	• RDF Description of the APAIS thesaurus • RDF description of the GCL • RDF description of the UKAT
Dan Brickley [SWDWG] http://danbri.org/		• Morten's FOAF/SKOS plugin for WordPress	
Dave Beckett http://www.dajobe.org/		• SKOS API	
Diego Ferreyra http://www.r020.com.ar/		• TemaTres	
Earle Martin http://downlode.org			• ISO 3166 RDF Representation • ISO 639 RDF Representation
Ivan Herman W3C SWA Lead / Centre for Mathematics and Computer Sciences (CWI), Netherlands http://www.w3.org/People/Ivan/			• Musicbrainz
Jakob Voss Verbundzentrale des GBV (VZG) / Common Library Network, Germany http://jakobvoss.de/	Publishing a Classification Scheme on the Semantic Web http://esw.w3.org/topic/SkosDev/ClassificationPubGuide		• IANA Language Subtag Registry in SKOS
John M. Linebarger Sandia National Laboratories,			• Wordnet in SKOS

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Albuquerque, USA			
Nikki Rogers Institute for Learning & Research Technology, University of Bristol, UK http://www.ilt.bris.ac.uk/aboutus/staff/staffprofile/?search=nr8262	<ul style="list-style-type: none">• SWAD-E (European Semantic Web) project http://www.w3.org/2001/sw/Europe/	<ul style="list-style-type: none">• SKOS API	

6. RECOMMENDATIONS FOR THE HIVE PROJECT

The HIVE (Helping Interdisciplinary Vocabulary Engineering) Project proposes an automatic metadata generation approach that dynamically integrates discipline specific controlled vocabularies and assists content creators (or professionals) with subject cataloging for the Dryad repository. This repository holds data of evolutionary biology, an interdisciplinary field that has proved to be hardly represented by a single vocabulary.

The aim of this section is the selection and grouping of those initiatives, tools, data and other achievements that could help the HIVE project researchers to accomplish the objectives and tasks necessary for the building of HIVE, mainly the vocabulary preparation and the vocabulary server development phases.

Vocabulary preparation phase:

For this phase, devoted to the conversion of the sample vocabularies to SKOS and the development of a conversion algorithm, at least two kinds of initiatives are going to be useful: on the one hand, those vocabularies already represented in SKOS related to the evolutionary biology, and on the other hand, the thesaurus creator or conversion tools with SKOS capabilities for those vocabularies that should be specifically converted to meet the HIVE Project goals.

A) Vocabularies in SKOS

In a previous assessment for the project, a keyword extraction from Dryad journal papers was performed, and the terms selected were mapped to several vocabularies. A partial match to the NBII Thesaurus, MeSH and LCSH vocabularies was found. Besides, the project proposal refers to the LCSH MARC 21, TGN and NBII vocabularies as needed to be converted to SKOS.

In this sense, any of the initiatives and SKOS Data reported in the section 5 of this document that deal with these mentioned vocabularies would be helpful, and they are summarized below:

- **LCSH:** there are several initiatives that have already converted the LCSH to SKOS, as the *lcsh.info* (by the own Library of Congress), the *HILT: High-level Thesaurus Project* of the Centre for Digital Library Research (CDLR), University of Strathclyde; and the *Terminology Services Project* of OCLC.
- **MeSH:** the University of Vrije's thesauri conversion initiative (<http://thesauri.cs.vu.nl/eswc06/>) offers the SKOS RDF graph of the Medical Subject Headings, as well as the perl conversion program used to convert it from the original XML schema. Besides, some projects have worked with SKOS representations of MeSH, as *BIRNLex of the Biomedical Informatics Research Network*, and also the *HILT: High-level*

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Thesaurus Project (CDLR, U. Strathclyde) and the *Terminology Services Project* of OCLC. Moreover, the *KEA (Keyphrase extraction algorithm)* software allows the automatic matching of indexer terms with several vocabularies, as MeSH (<http://www.nzdl.org/Kea/examples2.html>).

- **TGN:** in the case of the Thesaurus of Geographic Names, the *MultimediaN N9C E-Culture* project, has converted this vocabulary into RDF with its own tool *gettyconvert* (<http://e-culture.multimediana.nl/software/gettyconvert>), and the XML schemas are freely available in the package.
- **NBII:** in the early stages of the SKOS development by SWAD-Europe, a segment of the CSA/NBII Biocomplexity Thesaurus was converted to SKOS and integrated in the SKOS Thesaurus prototype. Now it has been completed and can be queried using the Biodiversity Thesaurus Web Services offered at (<http://nbii-thesaurus.ornl.gov/thesaurus/>).

Furthermore, and taking into account the main disciplines present in this evolutionary biology repository, other initiatives using science vocabularies could be interesting: for example, the *BIRNLex: a lexicon for neurosciences*, that deals with specific ontologies like the Gene Ontology, Reactome biological processes in humans), PATO (Phenotype and Trait Ontology) or the Subcellular Anatomy Ontology; the *Bio-zen ontology framework* that with Open Biomedical Ontologies (OBO). Also for some issues, concepts from the *GEMET (General Multilingual Environmental Thesaurus)*, already translated into SKOS, could be applied.

B) Conversion Tools and projects:

Several of the tools mentioned in the section 5.2. of this document, mainly in the *Vocabulary Development Applications* group, can be useful for the first phase of the HIVE Project.

The thesaurus creation tools *Tematres* and *ThManager*, and the ontologies editor *Protégé*, with SKOS export, view or editing capabilities, can be a choice to consider.

But surely, the SKOS conversion tools like *Annocultor* and *gettyconvert*, created for the *MultimediaN N9C E-Culture*, and those of the *University of Vrije* will be more helpful for HIVE, even though the last two are custom-built solutions for the specific vocabularies they dealt with. In any case, they will serve as an example or model for the development of the own HIVE conversion algorithm.

Also, the use of *stylesheets* to convert vocabularies into SKOS has been reported in several initiatives, for example for the translating of the LCSH (Harper 2008).

In the case of need of representation of a new or existing vocabulary in SKOS for the Dryad repository, and the subsequent concept scheme registration, a useful tool would be the NSDL Vocabularies Registry. This tool is able to export RDF graphs of the registered vocabularies.

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Finally, the *SKOS Validator Service* (<http://www.w3.org/2004/02/skos/validation>), available online at the SKOS webpage would be useful for the HIVE developers in order to check the validity and consistency of the SKOS vocabularies generated or converted.

Vocabulary Server Development

This phase will be focused in the building of a system that can search SKOS vocabularies, and a database that can store and present SKOS relationships for selection during cataloging. The specific tasks are: 1) Build a database system using that supports search and vocabulary enhancement functions; 2) Implement an algorithm that will automatically extract keywords from a document's abstract; and 3) Develop a module linking to Dryad's deposition of datasets for articles.

These features have been noticed in some of the projects and implementations of SKOS as well as in specific tools developed for them, gathered for the sections 4 and 5 of the report.

Firstly, the SKOS API should be considered as a mechanism to provide access to thesauri and other simple knowledge organisation systems via the web. Developed in Java, this API can be adopted and integrated in a SKOS vocabulary access web service.

Secondly, there are several projects that have developed tools or services for the **visualization, browsing and querying** of vocabularies. Some projects with web search services are: the *AIMS project* of FAO; the *CHOICE@CATCH Project*; the *HANAVI* graphical browser of the Univ. of Tsukuba; the *FACET Project* of the Hypermedia Research Unit, University of Glamorgan; the *HILT (High-level Thesaurus)*; the graphical representation of LCSH as Linked Data in *LCSH.info*; the *MultimediaN N9C E-Culture project*, or the SRU interfaces prototypes of the OCLC's *Terminology Services Project*.

In particular, the FACET, HILT and E-Culture projects offer interesting demonstrators that could serve as a model for the purposes of HIVE.

- The *FACET* project explored how a thesaurus can be integrated into the search interface and the potential of semantic expansion in querying collections indexed with controlled metadata. Even if they don't use SKOS for the web interface prototype they developed, it is a interesting example. This project also has done some research in the use of XPATH querying techniques to access XML/RDF data as SKOS thesauri, and they offer a web demonstrator.
- The *HILT* project also offers a pilot terminologies server and some valuable client demonstrators, using SOAP and SRW web technologies, and including a M2M demonstrator.
- Finally, the *MultimediaN N9C E-Culture* project has developed a demonstrator that uses the semantic search web-server Cliopatria (the same used later for the NewsML G2 Demo). This search engine offers access to several cultural heritage collections, matching the queries to multiple vocabularies and thesauri.

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Apart from these particular web services implementations, there is a project that could help in the development of a HIVE custom-built vocabularies search engine, *Squiggle*. As declares the project webpage (<http://squiggle.cefriel.it>), Squiggle is a “framework that supports the building of a domain-aware semantic search engine”, and “represents an abstraction for people who want to build a search engine in a particular domain and do not want to deal with low-level indexing and storing processes”.

Thirdly, for the specific task of **cataloguing of resources** in the repository, indexing with terms taken from the SKOS vocabularies previously stored, some other initiatives have been considered of interest, especially if they contribute with automatic indexing techniques.

Taking into account the repository platform used in Dryad, the *DSpace Ontology add-on* designed by the DSpaceDev@University of Minho should be considered. It allows the subject indexing of resources browsing and selecting terms from a SKOS vocabulary.

Moreover, the *KEA keyphrase extraction algorithm* will be useful for the automatic indexing of Dryad repository documents, as it allows the matching of the documents' phrases against the SKOS vocabularies in the system.

But for the case of those terms that don't match to any vocabulary, the techniques used for *SOBOLEO* could be a good starting point, as it allows the annotation of resources developing collaborative vocabularies in SKOS at the same time. Moreover, this tool offers browsing, search and editing features for the taxonomies generated.

Similarly, the model developed for the Biomedical Informatics Research Network (BIRN) offers a comprehensive approach with *BIRNLex*, an integrated ontology+lexicon that support semantically-formal data annotation, semantic data integration, and semantically-driven, federated query resolution.

Finally, as HIVE has to deal with several vocabularies, due to the subject heterogeneity in the evolutionary biology' Dryad repository, those projects addressing **vocabulary alignment** issues would be especially relevant.

In particular, those initiatives involving **automatic techniques** (as HIVE pretends to apply) should be more deeply analyzed:

- The *HILT: High-level Thesaurus* has developed an M2M terminology mapping server, to enable improved cross-repository searching, using SKOS Core to mark-up terminology responses. The mapping mechanism employed by HILT is similar to *switching* (use of a single terminology as an intermediary to translate requests from one scheme to another) but differs in that the switching terminology is also central to user *disambiguation* processes. They use the Dewey Decimal Classification (DDC) as the switching spine for searching, also permitting hierarchical browsing and the discovery of like terms within other terminologies.

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- The *MultimediaN N9C E-Culture project* has developed a prototype for the search and annotation of cultural heritage collections. They have upload RDF SKOS representations of several vocabularies, and the search engine has indexed all literals in the RDF triple store, allowing the quick find of all RDF literals matching the search terms. The prototype use distance metric techniques of the matching literal to enhance the results. (For more information, see the project FAQs: <http://e-culture.multimedian.nl/demo/www/faq.html>).
- The *LORNET, Theme 1 Interoperability of learning object repositories* initiative proposes an ontology mapping based framework that allows searching for learning resources using multiple ontologies. SKOS is used here for defining the ontologies used in the project (ACM CCS and an information course specific ontology) and for the mappings of concepts between them. Two search algorithms have been developed for repository searching, that use different strategies to infer matched concepts and rank results. With these algorithms, defining mappings for all concepts in the course ontology are not needed, as they use defined mappings to extrapolate missing mappings using the structure of both ontologies (Gasevic and Hatala, 2006).

Besides, other projects mapping vocabularies with SKOS, but with a likely **manual approach**, could also be observed:

- The *STITCH (SemánTic Interoperability To access Cultural Heritage)* Project is investigating semantic interoperability issues, especially in relation to conduct semantic searches across several digital heritage collections. A demonstration web browser has been developed using semantic correspondences (alignment) between description vocabularies. The vocabularies used in the collections have been represented in SKOS, and the relations between concepts have been coded by SKOS mapping features. They have used several strategies of lexical alignment, but apparently, the alignment has been done manually.
- The *AIMS project* of FAO has developed a semantic search service that makes use of mapped agriculture thesauri. The Agrovoc thesaurus has been converted into SKOS and is being mapped to two other vocabularies: the Chinese Agricultural Thesaurus (CAT) and the National Agricultural Library thesaurus (NAL). This mapping uses links inspired by the SKOS mapping vocabulary.
- In the *CrissCross project*, which main goal is the creation of a multilingual, user-friendly, thesaurus-based research vocabulary, the subject headings of the Subject Heading Authority Files (SWD) are linked with the notations of the Dewey Decimal Classification (DDC). The strength of correspondence of SWD terms and DDC classes is expressed by a code, the so-called "Degree of Determinacy", that shall be used for ranking in future retrieval systems. None automatic techniques are mentioned.
- *KoMoHe* supervised a terminology mapping effort, in which 'cross-concordances' between major controlled vocabularies were organized, created and managed. The mappings were

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created by researchers and terminology experts, however, the types of relations and relevance ratings proposed could be useful. This project doesn't use SKOS for the vocabulary mapping, but they plan on transferring the cross-concordance data to the SKOS format.

Besides the specific techniques used and described in the selected initiatives, we also recommend the consideration of other **ontology mapping techniques**. Interesting research efforts and trends, as the last paper referred in the section 4.2 (Nagy, Vargas-Vera and Motta, 2007), can be found at the proceedings of the *International Workshop on Ontology Matching* (3rd: <http://om2008.ontologymatching.org>, 2nd: <http://www.om2007.ontologymatching.org>; 1st <http://www.om2006.ontologymatching.org>).

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