A Network of Ontology Repositories

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Abstract. Ontologies and vocabularies are a key resource for creating interoperable metadata on the Semantic Web. To make the finding and using ontologies easier, the idea of Ontology Repositories have been introduced with current implementations including e.g. the NCBO Bioportal, ONKI and Cupboard. However, at the moment each ontology repository is a separate island with its own user interfaces and APIs. They also use varying ontology languages such as OWL, SKOS, RDF Schema and others. Due to this, global search, browsing, and inference over the repositories is difficult and generally not done. At the same time, there is a genuine need for different kinds of Ontology Repositories, each focusing on different kinds specific user-needs, different ontologies and different organizational requirements which can not be addressed by a single global implementation. Since there are benefits of having interoperability among the repositories, we have developed a loosely coupled Network of Ontology Repository (NOR) architecture that makes the repositories globally interoperable while maintaining their unique functionalities and strengths. To participate in the network, each ontology repository is required to implement a shared API. As a proof-of-concept, we present a global metasearch prototype for searching simultaneously hundreds of ontologies in the ONKI and NCBO Bioportal repositories.

1 Introduction

Ontologies and Ontology repositories have been considered a key resource for building a global infrastructure to enable the vision of the Semantic Web [1, 2]. Many ontology repository systems exist for publishing and sharing ontologies and vocabularies for content indexing, information retrieval, content integration, and other purposes, e.g. Cupboard [3], BioPortal [4], and ONKI [5]. Despite the benefits of having formally described, machine processable ontologies as the interlinking "glue" of the Semantic Web, when discussing ontology repositories one should not overlook the vast amount of other kinds of resource collections that define with various degrees of formality the concepts and give them URIs, that can be used for interlinking content. Examples of such less formal concept collections include vocabulary services, thesaurus browsers, registries of e.g. locations, people, languages etc., and the DBPedia [6]. For example, the BBC uses DBPedia (or Wikipedia) URIs as the interlinking URIs [7].

Currently each ontology repository is a separate island with no connections to other repositories. This means that, e.g. global search, browsing, or inference over the repositories can not be done, which creates a hindrance for using the ontologies efficiently, since the user have to know in advance which repository addresses her needs. For example, searching for the concepts with the label "fish product" from all existing ontology repositories around the Internet is currently not possible although many ontology repositories surely contain ontologies with matching concepts. On the other hand, general search engines such as Google[1] or general semantic search engines such as Swoogle[2] [8] are not focused on the specific ontology repository tasks such as finding the correct concept for annotation purposes, and may not index all relevant ontologies since they are not publicly available for business and other reasons.

That the user may not find the correct ontology or concept for one's needs has following consequences:

– The quality of annotations may decrease if the optimal concept is not found.
– Redundant new ontologies are created if the existing ontologies are not found.
– Interlinking of data decreases due to creating redundant ontologies.
– Merging data for semantic web applications becomes more difficult due to the need for ontology matching.

For the repository maintainers and ontology publishers the non-interlinked current nature of the ontology repositories means that:

– High quality ontologies might not be used as much as they should since they are unknown to some of the users.
– High quality repositories might be underused because they are not found by potential users.
– Repositories do not benefit from ontologies available in other repositories. For example, (automatic) linking to relevant concepts in other ontologies could help the users to find the best ontologies and concepts for each need.
– Ontology repositories are not acting as model citizens of the Semantic Web, since their ontological content is not interlinked as much as it could be.

Together the issues described above reflect the underlying problem of how to publish ontologies on the Semantic Web. There seems to be a lack of shared practices on how to publish ontologies on the web, as discussed also in [2]. We argue, that ontology publishing requires shared practices that address at least the following needs:

– The ontologies and ontology concepts should be easy to use as values (URIs) in metadata. The URIs should maintain their identity over time, because the content may be archived and relevant for a long time.

[1] http://www.google.com
[2] http://swoogle.umbc.edu

– Various ontology formats should be possible to use such as OWL, RDF Schema, SKOS and others. However, from the ontology repository interoperability point-of-view using different languages makes the usage of ontology repositories more difficult. Due to this, there should be also a shared dumb down language as a lingua franca between the repositories for presenting basic information about the concepts and ontologies to external applications.
– Using ontologies and ontology concepts should be easy to integrate to new and existing application. This implies a need for shared APIs and other ways to access ontologies, e.g. user-interfaces, JavaScript Widgets and integration to commonly used content and document management systems, such as Drupal and Office applications.

As a solution to the problem of how to access the repositories globally, and in the spirit of the Linked Open Data[3] [9], we propose a Network of Ontology Repository (NOR) architecture consisting of shared APIs and metadata schemas and shared practices for creating an interoperable network of ontology repositories.

In our work, we restrict our focus on the Semantic Web and RDF compatible ontology languages but we presume the ideas presented in this work can be of use also for developing ontology repositories for non-RDF ontology languages such as the Common Logic[4].

The work is partially based on our previous work on the national ontology library ONKI [5, 10] and is related to the open ontology repository (OOR)[5] intiative which aims at developing an interoperability infrastructure for ontologies [2].

In the following, we first argue why a single ontology repository is not a viable solution for addressing all ontology repository needs. Then we present the proposed NOR architecture. After this, a proof of concept implementation of the NOR is described. Finally, related work is discussed and contributions of the paper summarized.

2 Why a Single Ontology Repository is not Enough?

One solution for creating an interoperable network of ontology repositories would be to create one application that would address all the needs of ontology publishers and users. However, we argue that restricting the ontology network to a single ontology repository application is not a viable solution due to the following reasons:

Different ontologies and user needs require different functionalities in the ontology repository. For example, the ONKI repository is based on many different implementations of an ontology server to support different types of ontologies and different visualization needs as depicted in Fig. 1. Examples of different ontologies include e.g. general ontologies, geographical ontologies, and biographical

[3] http://linkeddata.org
[4] http://common-logic.org/
[5] http://ontolog.cim3.net/cgi-bin/wiki.pl?OpenOntologyRepository

ontologies. For example, the Bioportal has been designed originally to address the needs of the biomedical domain.

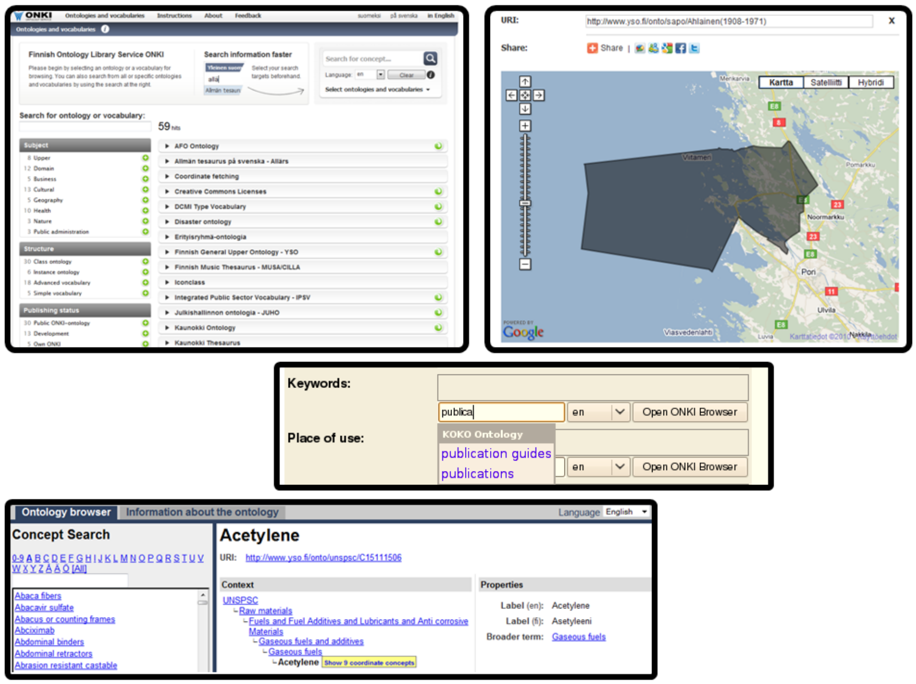

Figure 1. Different user interfaces of the ONKI repository, including ontology listing, map visualization for geographical ontologies, JavaScript Widget for concept search and concept hierarchy visualization.

All ontology repositories are not primarily ontology repositories. Many existing systems for publishing ontologies, thesauri or other kinds of concept registries exist, including e.g. content management systems such as Drupal[6] which have light-weight capabilities for maintaining and using thesauri and ontologies as part of Drupal websites. Other examples include DBPedia [6], semantic metadata registries such as the SAHA [11] and CultureSampo [12]. A single ontology repository system most probably will not replace all of the different systems that are used for maintaining ontologies and vocabularies of various degrees of formality. Therefore, integrating existing and future ontology repositories to the Network of Ontology Repositories should be a more viable way.

[6] http://drupal.org

Solving the interoperability problem on the general level now does not hinder the "markets" from choosing in future a single ontology repository implementation as the winner. At the moment, no single ontology repository has been chosen by all ontology publishers which means that there is an opportunity for the NOR. When the ontology repository technology matures, there might be a market leader that address the needs of the repository publishers and users.

Due to the reasons above, we argue that a network of ontology repositories is needed for making the repositories and potentially other relevant data sources interoperable and better accessible for the ontology users.

3 The Network of Ontology Repositories

Semantic Web ontologies are presented using RDF compatible languages such as OWL, SKOS and RDF Schema. Therefore they can be seen as Linked Data[7]. We argue that ontology repositories should follow the Linked Data principles and build ontology specific functionalities on them.

Figure 2 depicts an overview of the proposed architecture, where the "NOR API" defines the required functionalities of the ontology repositories such as:

- Using shared URI practices.
- Making different ontology language schemas interoperable.
- Additional APIs for accessing the ontology repositories in those ways that are not directly supported by basic Linked Data functionalities (such as SPARQL).

In the following, we discuss in details each issue. In addition, to participate in the network, metadata about the repository must be available in the NOR registry, to be able to find the repositories. In future, there could also be inter-repository functionalities (depicted in Fig. 2 as "NOR API #2") for example to inform other repositories about updates in authorative versions of ontologies.

3.1 Presenting an Ontological Concept

Ontology repositories contain ontologies represented using different ontology languages which have been chosen based on the modelling and inference needs. However, from the interoperability point of view, this creates a problem because the relations between different properties in different languages is not always known.

To avoid complicated mappings and inference especially in the case of hierarchical and other relations, we propose that each ontology repository should provide a normalized, dumbed down presentation of the ontology concepts in addition to the native format of the ontology. As the normalization language we suggest using SKOS.

[7] http://www4.wiwiss.fu-berlin.de/bizer/pub/LinkedDataTutorial/

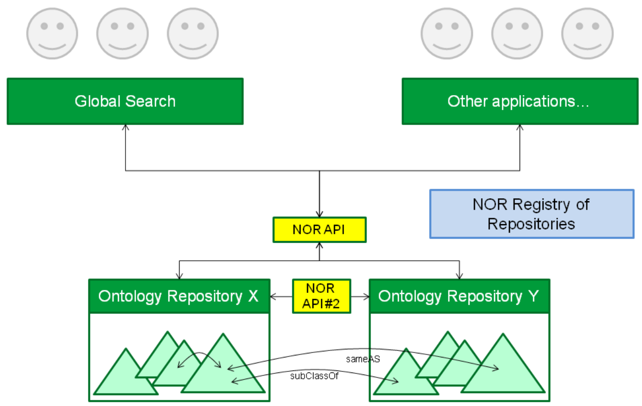

Figure 2. The general architecture of the Network of Ontology Repositories.

Hiding ontological details makes it easier for the applications using the NOR for e.g. displaying the concepts originating from different ontology repositories in a uniform way to the user. After finding an interesting concept, the user can be directed to the specific ontology repository with its full functionality for handling the specific ontology.

In addition, the ontology repository should provide a normalized concept lookup URL, which gets as a parameter the concept URI we are interested in. For example, to get the normalized view of the concept *yso:p907*, we would look up the following URL:

```
http://www.onki.fi/nor/concept?uri=http%3A%2F%2Fwww.onki.fi%2F
onto%2Fyso%2Fp907
```

which returns metadata about the given concept and also the concept description in the native ontology format (presented in Turtle format):

```
<http://www.onki.fi/nor/concept?uri=http%3A%2F%2Fwww.onki.fi%2F
onto%2Fyso%2Fp907>
   a skos:Concept;
   skos:prefLabel "fish"@en, "kala"@fi;
   skos:broader
     <http://www.onki.fi/nor/concept?uri=http%3A%2F%2Fwww.onki.fi
%2Fonto%2Fyso%2Fp6580>;

   #...additional properties about the concept in normalized format.

   nor:describes yso:p907.  # link to the native format
```

```
yso:p907
   a ysometa:Concept;
   ysometa:prefLabel "fish"@en, "kala"@fi;

   #...additional properties about the concept in native format.
.
```

To avoid adding any triplets or properties to the native format, we keep the native and normalized formats apart from each other, connected only by the *nor:describes* property.

In addition to Turtle, also other formats may and should be supported, including RDF/XML and presenting RDF as JSON.

3.2 Registry of Ontology Repositories

To find Ontology Repositories from the Network, metadata about the services is needed. Since ontologies on the Semantic web are typically presented as RDF and they are may (should) be interlinked, we propose using the Vocabulary of Interlinked Datasets (voiD)[8] for describing the ontologies available in the ontology repositories, with following extensions:

- *nor:endpoint*: for declaring the URL of the NOR API.

Additional information about the ontology such as the title and description may be expressed using e.g. the Dublin Core metadata schema, the Ontology Metadata Vocabulary (OMV)[9] and the upcoming Catalogue Vocabulary (dcat)[10]. Based on the metadata, e.g. a list of ontology repositories on the network can be published.

3.3 APIs for the Network of Ontology Repositories

In addition to the lookup URL described above, an ontology repository participating in the network may implement other methods, too. A network of ontology repositories would benefit from providing APIs and methods for e.g. searching, browsing, comparing and updating the ontology repositories. In addition, normal RDF and Linked Data access methods may be supported, such as providing a SPARQL endpoint. However, being a general RDF query language, SPARQL is not optimized for the Ontology Repository queries which may make using SPARQL difficult for the users and make the efficient usage of the Ontology Repository more difficult.

As an example of what the APIs may be, we propose the following API for making concept searches:

[8] http://rdfs.org/ns/void#
[9] http://omv2.sourceforge.net
[10] http://www.w3.org/egov/wiki/Data_Catalog_Vocabulary

– *search?q=[query]&l=[language]*: search for concepts

The search method is used for finding concepts matching the given query string and given language. The method returns a list of matching concepts. Later, additional parameters may be added, such as restricting the query to a specific ontology, to a specific part inside an ontology or a specific concept type.

We propose implementing the NOR API as a lightweight, stateless, and cacheable REST API that returns data using the JSON format. However, other web service technologies such as SOAP may also be supported.

4 The Proof-of-Concept Implementation

To test the Ontology Repository Network concept, we implemented a proof-of-concept prototype which provides a metasearch to the ONKI SKOS [13] servers and the NCBO Bioportal [4]. This allows the user to find the relevant concepts from all participating ontology repositories, without having to know in advance which repository to make the search to.

4.1 ONKI and Bioportal

The ONKI SKOS ontology server has been used for publishing over 70 ontologies in the Finnish Ontology Library Service ONKI [13, 5]. Even though ONKI SKOS supports especially vocabularies presented in SKOS, the server can be used for publishing ontologies presented in other languages too, such as OWL and RDF Schema. To access the different ontology servers, ONKI contains a front-end service that does metasearches to the ONKI SKOS back-ends using a REST API (see Fig. 3).

The ONKI3 Browser[11] is a global search and browsing user interface for accessing the ONKI SKOS back-end servers in a uniform way. For example, making a global query to all ontology servers can be done. The ONKI3 user interface was mostly implemented using PHP[12].

Another client is the JavaScript-based ONKI Selector widget [14] for adding ontological concept search to HTML forms which also is using the metasearch for finding the matching concepts.

A third simple client is the URI resolver for dereferencing the end-user's ontology concept URI requests to a suitable representation provided via the ontology repository network, such as HTML or RDF.

To make client implementation easier, a broker for accessing the back-end network was implemented. It provides a registry of ontology servers based on the ontology service metadata, a single access point for using the ontology server network and a cache[13] to speed up potentially slow HTTP requests to individual ontology servers. Based on the registry, the broker directs requests to relevant back-end ontology servers.

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[11] http://www.yso.fi/onki3/en/
[12] http://www.php.net/
[13] As a proxy cache we used Varnish: http://varnish-cache.org/

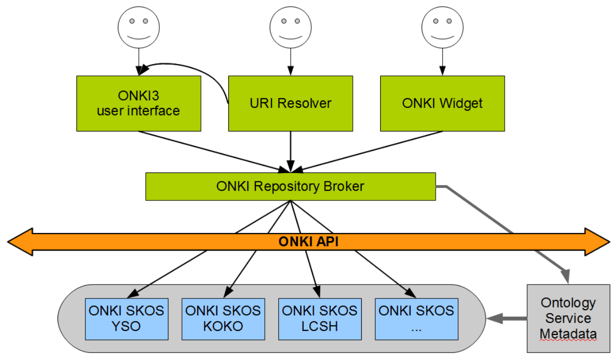

Figure 3. The ONKI architecture.

NCBO Bioportal is an open repository of biomedical ontologies which has been used for publishing over 200 ontologies[14] [4]. It provides functionalities such as concept and ontology search and browsing, peer reviewing the ontologies, and support for creating and viewing mappings between ontologies.

The ONKI SKOS and Bioportal provide APIs for accessing the ontologies, but the APIs act differently and return different kinds of responses. For example, to search for the concepts that matches the string "fish products" using the Bioportal's HTTP REST API[15], the queries has to be made to:

```
http://rest.bioontology.org/bioportal/search/fish+product?email=
example@example.org
```

which returns a Bioportal specific XML starting as following:

```
<?xml version="1.0" encoding="UTF-8"?>
<success>
 <accessedResource>/bioportal/search/fish+product</accessedResource>
 <accessDate>2010-12-13 01:20:02.405 PST</accessDate>
 <data>
  <page>
   <pageNum>1</pageNum>
   <numPages>1</numPages>
   <pageSize>5</pageSize>
   <numResultsPage>5</numResultsPage>
   <numResultsTotal>5</numResultsTotal>
   <contents class="org.ncbo.stanford.bean.search.SearchResultListBean">
    <searchResultList>
```

[14] http://bioportal.bioontology.org

[15] http://www.bioontology.org/wiki/index.php/BioPortal_REST_services

```
<searchBean>
 <ontologyVersionId>42295</ontologyVersionId>
 <ontologyId>1427</ontologyId>
 <ontologyDisplayLabel>Read Codes, Clinical Terms
                       Version 3 (CTV3) </ontologyDisplayLabel>
 <recordType>RECORD_TYPE_PREFERRED_NAME</recordType>
 <conceptId>http://purl.bioontology.org/ontology/RCD/Ub004</conceptId>
 <conceptIdShort>Ub004</conceptIdShort>
 <preferredName>Fish products</preferredName>
 <contents>Fish products</contents>
</searchBean>
...
```


In the case of ONKI SKOS, the search is made by accessing the ONKI SKOS server's REST API method:

```
http://www.yso.fi/onto/yso/rest/search?q=fish+product&l=en
```

where l defines the language of the query string q. The ONKI SKOS responds with a JSON message starting as follows:


```
{"results":[
  {"namespacePrefix":"yso", "label":"fish products",
   "uri":"http://www.yso.fi/onto/yso/p6499",
   "serkki":"yso:fish products"
  }],
 "metadata":{ "containingHitsAmount":1, "moreHitsAmount":0 }
}
```


Both Bioportal and ONKI provide methods for getting more information about each concept (or "term") based on the concept's URI and the containing ontology identifier (and in Bioportal, also the specific ontology version).

ONKI SKOS has the method *getFullPresentation* which returns all information about a given concept, such as the prefered labels, alternative labels, the transitive parent concept tree and related concepts. In Bioportal, to our knowledge, such method does not exists which means that especially for finding the parents, one has to do as many separate HTTP REST requests as there are parents.

Example of the ONKI SKOS getFullPresentation response (abbreviated):


```
{
"getLabels":[
  {"propertyUri":"http://www.yso.fi/onto/yso-meta/2007-03-02/prefLabel",
   "propertyLabel":"Asiasana", "label":"fish products", "lang":"en"},
  {"propertyUri":"http://www.yso.fi/onto/yso-meta/2007-03-02/prefLabel",
   "propertyLabel":"Asiasana", "label":"kalavalmisteet", "lang":"fi"},
  ],
```

```
"getProperties":[
  {"propertyUri":
      "http://www.yso.fi/onto/yso-meta/2007-03-02/associativeRelation",
   "propertyLabel":"Related concept",
   "objects":[
     {"label":"fish", "uri":"http://www.yso.fi/onto/yso/p907"},
     {"label":"fish dishes", "uri":"http://www.yso.fi/onto/yso/p6498"},
     {"label":"food products", "uri":"http://www.yso.fi/onto/yso/p21001"}
     ]},
  ],
"getParents":[
  {"indent":0, "conceptUri":"http://www.w3.org/2002/07/owl#Thing",
   "label":"Thing*"},
  {"indent":1, "conceptUri":"http://www.yso.fi/onto/yso/p4205",
   "label":"yso-ksitteet",
   "parentUri":"http://www.w3.org/2002/07/owl#Thing"},
...
  {"indent":8, "conceptUri":"http://www.yso.fi/onto/yso/p6499",
   "label":"fish products",
   "parentUri":"http://www.yso.fi/onto/yso/p9248"}],
]}
```

Independently of the language each ontology is presented in, each concept is always returned in the format described above, which is partially inspired by the SKOS language.

For example, the ONKI SKOS URI for the YSO concept “fish products” is following:

`http://www.yso.fi/onto/yso/p6499`

The URIs are designed to contain both the containing ontology identifier (*yso* refers to the Finnish Upper Ontology YSO) and act as version identifier *p6499*. When querying the ONKI server,

In Bioportal the mechanism for identifying the concepts is based on the combination of the concept URI, ontology version ID and the ontology ID. For example, to return the exactly same version of the concept “Fish products” displayed in the Bioportal example above, the ontology version (42295), ontology id (1427) and the concept identifier (http://purl.bioontology.org/ontology/RCD/Ub0O4) has to be known.

4.2 Metasearching the Network of Ontology Repositories

Since the ONKI front-end [5] have already designed to function as a front-end for back-ends which are (mostly) ONKI SKOS servers, the prototype of a Ontology Repository Network was implemented by creating a wrapper for Bioportal which implements the ONKI SKOS APIs search and getFullPresentation methods.

The wrapper was implemented using PHP and it provides following ONKI API methods:

- *s*earch: keyword search for concepts
- *g*etFullPresentation: returns the details of a given concept

When calling the wrapper, it makes requests to Bioportal, parses Bioportal's XML message and transforms them to the ONKI JSON format displayed above.

In addition, to make the ONKI front-end aware of the Bioportal back-end, the Bioportal was described with ONKI metadata, most importantly the title of the ontology (rdfs:label) and the URL of the wrapper (onki:backendUrl). Example of the metadata description is below:

```
onto:bioportal rdf:type onki:Ontology ;
  rdfs:label "Bioportal"@fi, "Bioportal"@en;
  onki:backendUrl "http://www.yso.fi/nor/wrappers/bioportal/" ;
  onki:description "Use BioPortal to access and share ontologies
           that are actively used in biomedical communities."@en;
  onki:abbreviation "biop" ;
  onki:language <http://www.lingvoj.org/lang/en> ;
  onki:browser onki:true ;
  onki:group onki:groupPub ; onki:status onki:alpha ;
  onki:subject onki:SubjectOntologyNaturalScience ;
  onki:type onki:AdvancedVocabulary ; onki:uriIsUrl onki:false ;
  onki:visible onki:true ; onki:webservice onki:true .
```

4.3 Example Query

Figure 4 presents the ONKI user interface displaying the result of an example metasearch query for "fish product" to the Bioportal and ONKI SKOS backends. For demonstration purposes, the Bioportal hits are presented in the user inferace by the name "Bioportal" but for actual use, this should be replaced with the name of the respective ontologies.

5 Discussion

Compared to more general methods of accessing RDF data, such as SPARQL[16] and Linked Data [9], the NOR approach focuses on ontologies. For example, when querying for the concepts with the NOR search API, one does not need to know what RDF properties are used in the data to express the relevant labels. In addition, the ontology repositories can be optimized to respond quickly to specific API queries. However, due to the idea of presenting a normalized view on the ontologies, querying the data via SPARQL and browsing the ontology repositories as linked data becomes easy. For example, one does not have to

[16] http://www.w3.org/TR/rdf-sparql-query/

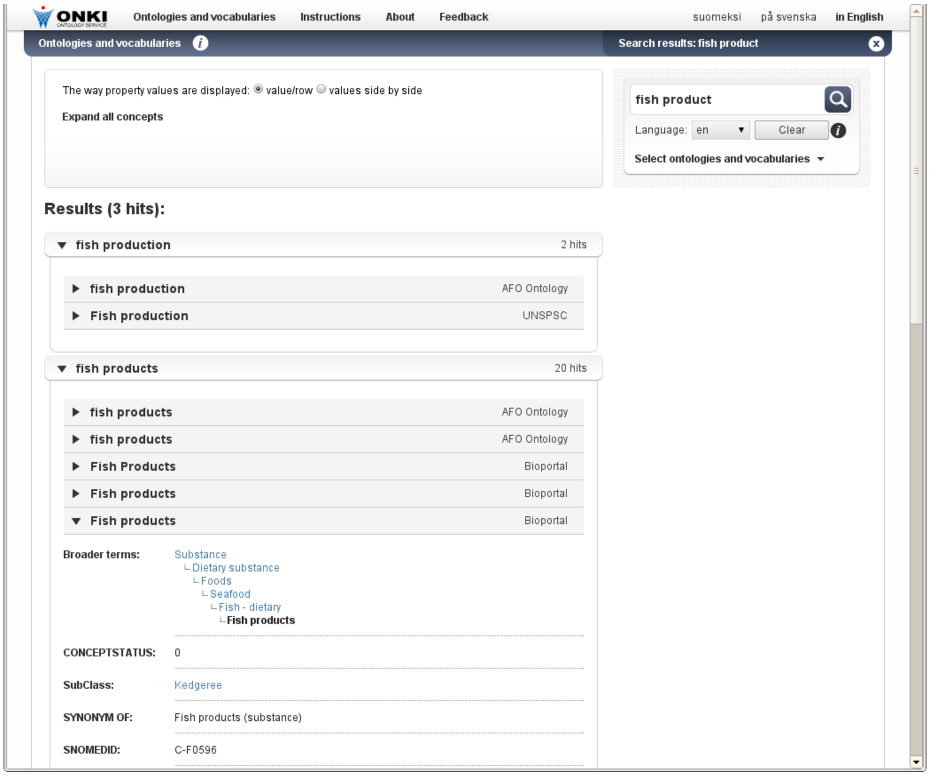

Figure 4. The proof-of-concept implementation: results from ONKI SKOS and Bioportal presented using the ONKI3 metasearch interface.

know which specific hierarchical relation (e.g. *rdfs:subClassOf* or *skos:broader*) has been used, because the normalized hierarchical relation can always be queried for.

APIs for accessing ontologies and vocabularies presented previously include the SKOS API[17] and the OWL API[18]. Compared to them, the NOR aproach provides a higher abstraction, independent from specific ontology languages, and a very light-weight and simple APIs. Compared to the API's of BioPortal [4], Swoogle[19] [8] and Watson[20] [15], the goal of NOR is to create a network of ontology servers based on a shared API that is implemented by all services. Therefore, the NOR API focuses on a few basic methods that reflects the basic functionality of ontology repositories, e.g. concept search.

[17] http://www.w3.org/2001/sw/Europe/reports/thes/skosapi.html
[18] http://owlapi.sourceforge.net/
[19] http://swoogle.umbc.edu/
[20] http://watson.kmi.open.ac.uk/

Ontology servers such as BioPortal and Cupboard support publishing interlinked ontologies, but the ontologies have to be uploaded into a centralized service for a global search. In contrast, in the NOR approach ontologies can be published using a ontology service that is optimized for the specific ontology and the user's needs while publishing the ontology service's basic functionality via the NOR API to connect the ontology service to a global network of ontology services.

The loosely coupled NOR architecture has turned out to be a flexible solution in our experiments with the ONKI system and our proof-of-concept presented in this paper which makes it easy to implement additional clients when needed. Making multiple HTTP requests to back-end servers may be slow in the worst case, but in our test implementation this lag has not been a problem.

To conclude, this paper argues that the various ontology repositories on the web should be made accessible using a shared API that would provide a simple but universal methods for accessing the ontology content in a uniform way. As a solution, we propose the NOR API.

Future work include connecting additional ontology repositories to the network and developing further the APIs and the normalized ontology presentation schema. In addition to ontology repositories, also other vocabularies and registeries would be relevant to be added to the metasearch of concept URIs. For example, DBPedia's (Wikipedia) URIs are often used as values in Linked Data metadata. Being a part of the Ontology Repository Network search would add benefits for the end-user when trying to find the best concepts (and their URIs) for their annotation and information retrieval needs.

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