Semantic Web Techniques for Multiple Views on Heterogeneous Collections: a Case Study

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Abstract. Integrated digital access to multiple collections is a prominent issue for many Cultural Heritage institutions. Metadata describing diverse collections must be interoperable to achieve integrated access. Aligning the controlled vocabularies that are used to annotate objects in different Cultural Heritage collections could provide such interoperability. In this paper, we present an experiment where we apply Semantic Web techniques to match the vocabularies of two collections. We discuss the steps that are required for such matching, namely formalizing the initial resources using Semantic Web languages, and running ontology mapping tools on the resulting representations. In addition, we present a prototype that enables one to browse the two collections using the obtained alignment while still providing the user with the original vocabulary structures.

1 Introduction

Integrated access to multiple digital collections is a prominent issue within many research departments of Cultural Heritage (CH) institutions. These collections contain different kinds of objects, with different subjects, are described using different annotation schemes and controlled vocabularies and might be stored in and be accessible via different information systems; they are heterogeneous.

To access several of such sources via one portal, one first needs to obtain syntactic interoperability by building a system that can get information from all sources simultaneously, using standard protocols or shared metadata schemes. However, to maximally use the original resources, integrated systems should also take the semantic differences between collections into account. An example of these semantics is the structure of the vocabularies used for description; e.g. what does a relation between "geography" and "social geography" mean? Proper links between the vocabularies can be exploited in an integrated system. Establishing these links between collections and vocabularies is in the remainder of this paper referred to as the *semantic interoperability* problem.

This problem is similar to ontology alignment, on which the *Semantic Web* (SW) research community recently started to work intensively: CH vocabularies are similar to ontologies.

The general aim of our research is to determine to what extent the current SW techniques can solve heterogeneity issues in the CH sector. Our research involves an experiment for providing integrated access to two heterogeneous collections, the Illuminated Manuscript collection[4] from the Dutch National Library (KB), and the ARIA Masterpieces collection[5] from the Rijksmuseum in Amsterdam. In this paper, we describe the concrete steps of our experiment. First, to provide integrated access to semantically linked CH collections, a conversion to generic formats, such as RDF(S)[6] and SKOS[7], was required. Second, having computer-readable representations, we could align them. We turned to two off-the-shelf ontology mappers (S-Match[1] and Falcon[10]) and evaluated their use for aligning CH controlled and structured vocabularies. Third, automatically found correspondences were used in a special interface we implemented to browse different vocabularies and to retrieve documents from several collections in parallel, based on the multi-faceted browsing paradigm.

As said, the goal of the research described in this paper is to evaluate the potential and limits of current Semantic Web technology for integrating multiple CH collections with heterogeneous vocabularies. Our main research questions are:

1. Are the current SW techniques suitable for solving this integration problem? and
2. Are there specific CH problems that need particular efforts from the SW community?

The paper is structured as follows. In Section 2 we introduce our case study, by describing the two collections we aligned. In Section 3 we work out our solution to the problem from a practical perspective. In Section 4 we then discuss the relevance of our findings for both CH and SW practitioners, before we relate our work to existing work, and conclude.

2 Case study: Illuminated Manuscripts and Masterpieces

The Illuminated Manuscripts and Masterpieces collections contain objects such as images, drawings, books and/or sculptures. Most interesting for us is the heterogeneity of the vocabularies used to describe these collections.

The Manuscripts collection contains 10.000 medieval illuminations which are, in addition to the standard bibliographical information, annotated by subject indices describing the content of the image. These indices come from the Iconclass classification scheme, a 25.000 element vocabulary with iconographical analysis as main purpose. An Iconclass *subject* consists of a "notation" – an alphanumeric identifier used for annotation – and a "textual correlate" – e.g. `25F9 mis-shapen animals; monsters`. Subjects are organized in nine hierarchical trees. Other

[4] http://www.kb.nl/kb/manuscripts/

[5] http://www.rijksmuseum.nl/collectie/index.jsp?lang=en

[6] http://www.w3.org/RDF/

[7] http://www.w3.org/2004/02/skos/

features are associative "cross-reference" links as well as mechanisms for subject specialisation, such as "keys" – e.g. `25F9(+33)` would refer to the head of a monster. Finally, subjects have simple "keywords" used for retrieving them: `25F9` is thus linked to "monster" and "shape", amongst others. It is important to note that textual correlates are often in the form of glosses, e.g. "Noah's sacrifice; various animals are offered, possibly a lamb, a dove and a ram (often combined with the rainbow of the covenant)".

The Masterpieces collection contains 700 objects such as paintings and sculptures and its subjects are indexed using the ARIA "catalogue". This controlled vocabulary, conceived mainly as a resource for browsing, consists of about 500 terms and three sub-vocabularies. The first is intended for the layman, and contains subjects like `Man`, while the second is for more advanced users: it contains similar but finer-grained subjects like `Male portraits`. A third very small list – 6 types of objects, like `Sculpture` – is used as a high-level entry point to the system. The only "semantic" information found in this catalogue consists of specialisation links within the first two vocabularies, that can be interpreted as classical "Broader Than" relationships. The hierarchies are only two levels deep and there are occurences of multiple inheritance.

3 Performing the case study

In this section we describe our approach for providing access to the integrated Illuminated Manuscripts and ARIA Masterpieces collections. Figure 1 shows our framework in a schematic way. In a first step we transform both collections and their respective thesauri into Semantic Web compliant representation languages. Secondly, we create an alignment between the two thesauri using existing mapping technology. Finally, we build a browser to access the linked collections.

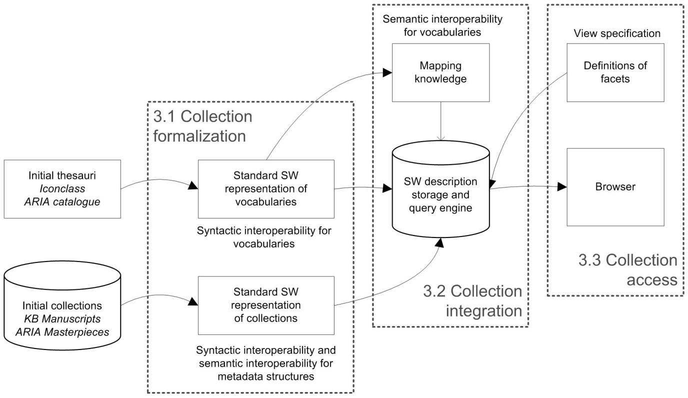

Semantic interoperability for vocabularies
Mapping knowledge
View specification
Definitions of facets
3.1 Collection formalization
Initial thesauri
Iconclass
ARIA catalogue
Standard SW representation of vocabularies
SW description storage and query engine
Browser
Syntactic interoperability for vocabularies
3.3 Collection access
Initial collections
KB Manuscripts
ARIA Masterpieces
Standard SW representation of collections
3.2 Collection integration
Syntactic interoperability and semantic interoperability for metadata structures

Fig. 1. The different steps of our experiment

3.1 Collection formalization

This case study supplies two types of CH resources that need transformation: the controlled vocabularies and the collections themselves.

Converting controlled vocabularies There have been substantial methodological efforts concerning the conversion of CH vocabularies into SW formats. Similar to [3], we handle the knowledge acquisition process in two steps: first, analysing the sources our use-case provided, and second, formalizing the knowledge they contain. This last step involves two consecutive conversions; first get a standard and then an application-specific representation.

Analysis. We had the controlled vocabularies as well as significant expert feedback at our disposal. As the vocabularies differ significantly in nature and use, we expected them to be difficult to represent using the same formal apparatus. The question was whether to take all peculiarities of the respective vocabularies into account, or whether to turn to some standard model. We opted for the latter, as we wanted to test a process – both for representation, alignment and exploitation – that could be generalized to a wider range of vocabularies.

Standard formalisation The SKOS (Simple Knowledge Organisation System) initiative provides a standardized model to encode the most common knowledge organization schemes, such as thesauri or classification schemes, in SW languages. SKOS is an RDF vocabulary that is currently being developed within the W3C Semantic Web activity. ARIA proved almost fully compatible with the SKOS schema. We only managed to convert Iconclass partly, namely its subjects. SKOS could not cope with Iconclass idiomatic elements, such as keys.

Application-specific formalisation Tools such as storage engines or browsers should interpret the SKOS files in accordance with their intended semantics. This often requires tweaking, e.g. to make our generic RDFS engine deal with the transitivity of the SKOS `broader` relation we had to interpret it as a sub-property of RDFS `subClassOf`.

Converting collection elements Our main focus being description *vocabularies*, we just used the description *structures* as they were in the orginal collections, without enforcing a unified scheme like Dublin Core. From the two metadata schemes we easily constructed small metadata ontologies in RDF Schema.

3.2 Collection integration

Having formalized our CH vocabularies in SW-compliant representations has the advantage that we can use existing ontology mapping tools to align them. We apply two state-of-the-art ontology mappers, Falcon and S-Match.

Falcon [10] is one of the best performing tools [8] for aligning complex RDFS/OWL ontologies. It relies on a combination of lexical comparison and graph-matching techniques. First, it compares concepts based on the set of weighted terms derived from their lexical "environment": their own identifiers, labels, comments, but also the ones of their immediate neighbors – parents, children – in the ontology. These similarities are used as input for the second step, which exploits a graph representation of the semantic information and matrix computation processes to finally return equivalence links between the concepts and relations of the compared ontologies.

S-Match [1] has been developed for mapping vocabularies represented as trees. It has a modular approach where a *lexical* matching component, a background-knowledge component ("*oracle*") and a *structure-based* mapping module all contribute to computing a mapping between the input trees. In S-Match default configuration, Wordnet[9] is used as the background knowledge component.

S-Match is not a general ontology mapper, but specializes on hierarchical classification trees used to structure the access to documents. S-Match core mapping method exploits the fact that the meaning of a concept in such a tree is determined by the concepts in the path to the root. Based on the lexical component and the oracle, each concept is associated with a propositional formula representing all its "available meaning". The mapping relations are then determined by the logical relations between the formulas for the concepts of the to-be-aligned classification trees.

Mapping results In table 3.2 some good mappings produced by S-Match are shown, where the first mapping was mainly produced based on lexical mapping, the second using stemming, and the third making use of background knowledge.

IC notation	Iconclass textual correlate	Relation	ARIA label
23L	'the twelve months represented by landscapes'	Less General	'Landscapes'
25A271	'(map of) the North Pole'	Less General	'Charts, maps'
23U1	'calendar, almanac'	Less General	'Publications'

Table 1. Some good S-Match mapping results

However, mapping thesauri proved to be difficult for both mappers, and the overall results were less than satisfactory. Evaluation measures for mapping results depend on their intended use. Regarding our intended browsing interface precision is more important than recall, because we do not want to confront users with useless links. For S-Match a precision of 46% is obtained on a selected subset of Iconclass (1500 concepts) and the complete ARIA thesaurus (500 concepts); 46% of the mappings were correct. Falcon reached a precision of only 16%.

[8] In the OAEI - Ontology Alignment Evaluation Initiative 2005

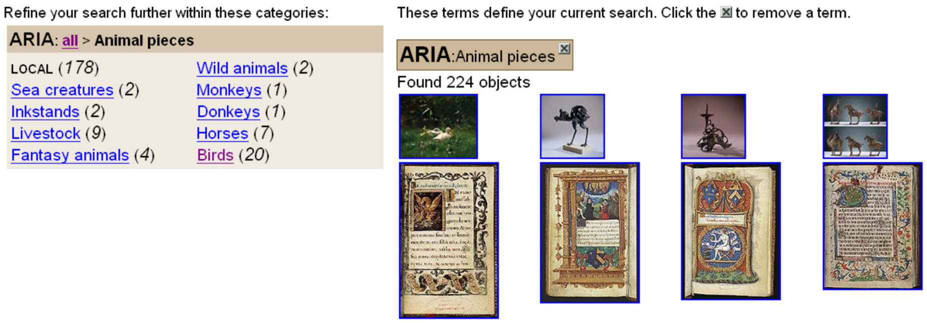
[9] `http://wordnet.princeton.edu/`

3.3 Collection access

We implemented a multi-faceted browsing (MFB) framework to evaluate and explore the results of our mapping effort. MFB involves constraining search criteria along – usually orthogonal – aspects of a collection called *Facets*. Here we tuned the MFB paradigm in an atypical way, since we used one category (subject) for defining several facets. Such a setting is possible because objects are often annotated by several subjects. So using one facet to search for "monkey" and another for "landscape" could retrieve pictures of a monkey in a landscape.

For searching through the integrated collections we explored three different views on integrated collections: *single*, *combined*, and *merged view*.

The *Single View* presents the integrated collections from the perspective of just one of the collections. The elements of the other collection are made accessible by means of the correspondences between their subject annotations and the concepts of the current view.



Refine your search further within these categories:

ARIA: all > Animal pieces

LOCAL (178)	Wild animals (2)
Sea creatures (2)	Monkeys (1)
Inkstands (2)	Donkeys (1)
Livestock (9)	Horses (7)
Fantasy animals (4)	Birds (20)

These terms define your current search. Click the ☒ to remove a term.

ARIA:Animal pieces ☒

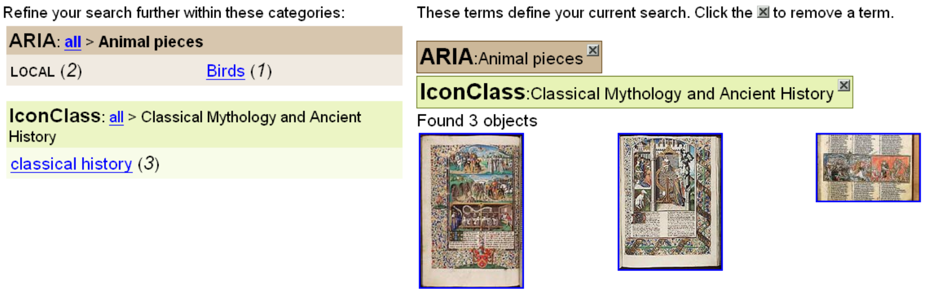
Found 224 objects

Fig. 2. Single View: Using the ARIA thesaurus to browse the integrated collections

In the screen capture (figure 2) the first four pictures come from the Rijksmuseum, the others are Illuminated Manuscripts. Browsing is done solely using the ARIA Catalogue, i.e. these illuminations have been selected thanks to the automatically extracted mapping between ARIA concept "Animal Pieces" and Iconclass "25F:animals".

The *Combined View* provides simultaneous access to the collections through their respective vocabularies in parallel. This allows us to browse through the integrated collections as if it was a single collection indexed against two vocabularies.

In figure 3 we made a subject refinement to ARIA "Animal pieces", and narrowed down our search with Iconclass to the subject "Classical Mythology and Ancient History". Only three Manuscripts matched these criteria. Notice that we browse according to a "biological" criterion using ARIA, and a "mythological" one from Iconclass to come to our results.



Refine your search further within these categories:

ARIA: all > Animal pieces

LOCAL (2) Birds (1)

IconClass: all > Classical Mythology and Ancient History

classical history (3)

These terms define your current search. Click the ☒ to remove a term.

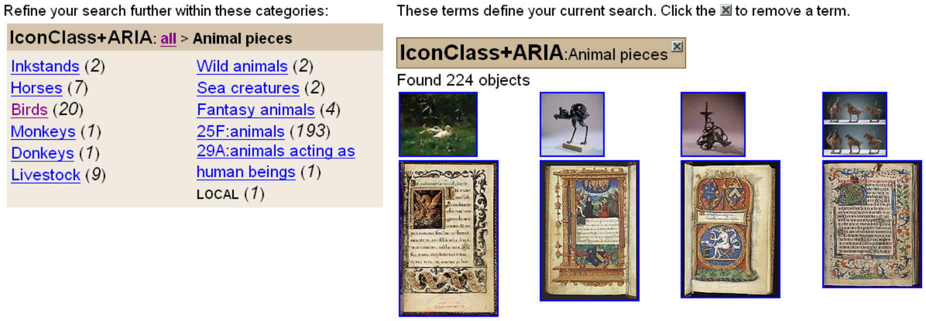
ARIA:Animal pieces ☒

IconClass:Classical Mythology and Ancient History ☒

Found 3 objects

Fig. 3. Combined View: Using ARIA and Iconclass to browse the integrated collection

The *Merged View* provides access to the collections through a merged thesaurus combining both original vocabularies into a single one, based on the links found between them in the automatic mapping process.



Refine your search further within these categories:

IconClass+ARIA: all > Animal pieces

Inkstands (2) Wild animals (2)
Horses (7) Sea creatures (2)
Birds (20) Fantasy animals (4)
Monkeys (1) 25F:animals (193)
Donkeys (1) 29A:animals acting as human beings (1)
Livestock (9) LOCAL (1)

These terms define your current search. Click the ☒ to remove a term.

IconClass+ARIA:Animal pieces ☒

Found 224 objects

Fig. 4. Merged View: Using a merged thesaurus to browse the integrated collection

For figure 4 we made the same selection as for the "single view" case. But notice that the "merged view" now provides both ARIA concepts such as "Birds" and an Iconclass concepts "29A:animals acting as human beings" for further refining our search. The mapping primitives determine the merging: two concepts that are identified to be equivalent are merged into one new concept, and if the mapping determined that a concept from one scheme is broader than a concept in the other scheme, the second concept is added as a child of the first.

Prototype details The design of our browser was inspired by the Flamenco search interface framework [2]. Its implementation used SWI-Prolog and the Sesame RDF repository[10] for storage and querying.

[10] Available on `http://www.openrdf.org`

4 Lessons learned

The main goal of our research was to find out to what extent SW techniques can solve heterogeneity issues when integrating multiple CH collections.

The general conclusion is positive: in a relatively short time we managed to implement an integrated browsing environment that was built purely on accepted standards for representing data, and which used existing tools for storage, querying and mapping. However, there is more to be learned for CH collection managers and developers of SW tools alike. In this section, we first try to answer questions concerning the practical relevance of chosen techniques and tools: to which extent can CH use-cases be successfully addressed by such solutions? We then explore the problems raised by our experiment from the point of view of SW researchers. Is our approach methodologically and technologically sound?

4.1 A Cultural Heritage perspective

Conversion Process Implementing a realistic process for going from CH resources to SW-compatible formats was successful, but often non-trivial.

Conversion and standards for CH vocabularies CH vocabularies often rely on complex models that are non-standard, which can hinder the conversion process. Especially for Iconclass some modeling decisions had to be made. For example, for *notations* we used the SKOS `prefLabel` property to enforce the necessary uniqueness constraint, even though notations, such as `25F9`, definitely miss the lexical flavor to make them proper *terms* e.g. `mis-shapen animals; monsters`. Even worse, some features could not be represented at all, like *keys* or the additional network of *keywords*. Potentially interesting information had to be sacrificed for the sake of genericity, which illustrates the trade-offs of using standards.

Ontology mapping vs. thesaurus mapping For our case study we applied off-the-shelf SW ontology mappers. However CH controlled vocabularies have features that make them really different from ontologies, e.g. glosses for describing concepts instead of simple terms. Here we describe the repercussions these peculiarities have on alignment quality.

Mapping poorly structured schemes Most ontology mappers rely on structure-based comparison using ontology semantics: subsumption relations, properties, etc. However, thesauri have less strictly defined semantic relations and their consistency is not always enforced. Because of this and the formalisation step, in which we lost some information, the only usable structural information present in our thesauri is the broader and narrower term hierarchy.

Falcon heavily exploits structure components usually present in expressively modelled ontologies. An analysis of the few correct results from Falcon shows that the lexical mapping works fine, but that the reliance on graph-based techniques usually contributes negatively to the overall process.

S-Match produces much better mapping results, as it was purpose-built for thesaurus-like structures. Nevertheless, the influence of the difference of the depth levels in both thesauri has unfortunate consequences: the fact that S-Match uses the full path of a classification tree for the mapping implies that its output is almost always of the form Iconclass-concept $\sqsubseteq$ ARIA-concept. For browsing, this is very damaging, as it constrains the way a user can specialize her queries: once she is browsing Iconclass subjects, she cannot find ARIA specialisations anymore.

Gloss features and concept matching The gloss features of concepts cause two anomalies to occur: 1) natural language meaning of a sentence is not interpreted, and 2) the meaning of single terms is not disambiguated by the remainder of their gloss, and thus interpreted as if denoting concepts on their own.

IC notation	Iconclass textual correlate	Relation	ARIA label
23H	'seasons of the year represented by concepts other than [...] landscapes [...]'	Less General	'Landscapes'
29D	'natural forms in stones, wood, clouds'	Less General	'Jewellery'

Table 2. Some bad S-Match results

An example of a bad match caused by lack of natural language interpretation is the first mapping in table 2: S-Match does not interpret "other than", which causes `23H` to wrongly match `Landscapes`.

Using Wordnet as background knowledge sometimes also leads to finding irrelevant links based on comparing single words, which could have been disambiguated by the other words found in the glosses. In table 2, 'Jewellery' would legitimately map to precious stones, but the other tokens in `29D` should have provided enough information to disambiguate between the different kinds of stones. An option for improvement would be to focus on smaller but more relevant pieces within Wordnet, e.g. taking only closest siblings into account.

4.2 A Semantic Web perspective

Generalizability. The *Semantic Web* claims to provide generic solutions. Therefore, the question arises whether it would be easy to reproduce what we did with new collections. Surely, we would benefit from our past experience, and the SW frameworks proved to be flexible enough to cope with different representational choices. But the transformation and mapping process would remain case-study dependent in at least two ways: First, the conversion effort depends on technical and functional requirements, such as the choice of *tools* and *tasks*. Second, both conversion and alignment processes are dependent on the CH *resources*. Take for example the influence of the structure of the vocabularies on the mapping process we discussed in the previous section.

Role of standards. In our approach the role of SKOS was crucial. Such a standard helps to integrate the different components of a framework. It also contributes to improving the extendability of the framework: for example, an additional SKOS-encoded thesaurus could be integrated easily in our tools.

The lack of *de facto* standards for alignment tools was a prominent problem. S-Match takes as input indented trees, which caused an important loss of information. Falcon does better, as it admits expressive standard RDF/OWL ontologies. For output things are even worse: Falcon outputs links in a standardized syntax, but its semantics are unclear. Again, S-Match was less generic, as its output is an ad-hoc non-standard format.

Methodological process guidance. The SW community already got concerned with conversion and deployment of CH vocabularies, and has proposed guidelines. Van Assem et. al. [3], for example, advocate three conversion steps. In the first step, the original vocabulary is translated into an RDFS/OWL model that mirrors the original structure as precise as possible. In the second step, one interprets the model so that intended semantic properties can be explicitly assigned to the RDFS/OWL representation. Finally, one can represent the vocabulary using a standard model, such as SKOS.

In our experiment we took this process as a guidance, although, focusing on genericity and implementation matters, we only applied its last two steps. However, for mapping purposes, the process itself might be questionable. On the one hand, using a standard model can help aligning vocabularies: a basic part of the integration process is partly dealt with by conversion. On the other hand, in order to give alignment tools more information for mapping a special conversion step for each controlled vocabulary could be beneficial.

Scalability. SW solutions are often criticized for their performing poorly against massive data sets, which are common in the CH world. Indeed, as Falcon uses a complex algorithm, it was practically impossible to have it run on complete Iconclass. Some division had to be done beforehand. However, S-Match performed better: it took five hours to achieve a complete alignment, which is not a problem since our application does not need to compute mappings at runtime.

5 Related Work

Our case has been influenced by portal projects like The European Library[11] and the Memory of the Netherlands[12]. But these do not use correspondences between vocabularies, though this problem has already been identified in the Digitial Library field [6]. Some DL projects like MACS[4] or RENARDUS[13] have used mappings, but they still relied on manual alignment, costly and possibly imprecise. We did want to explore the use of different, automatic alignment of

[11] http://www.theeuropeanlibrary.org

[12] http://www.geheugenvannederland.nl

[13] http://www.renardus.org

concept schemes. This is actually a common idea, especially in the SW community which has produced a number of dedicated tools [8]. It has even already been explored in the thesaurus field [5]. However, these methods usually lack concrete experiments that would assess the feasibility of integrating them in deployed applications.

Our approach is thus close to settings like [7] or [9] that try and apply SW techniques to concrete (CH) cases, except for our focus on automatic alignment. One shall notice that [7] also propose faceted browsing inspired, as we were, by the Flamenco framework [2]. We could have tried to re-use these solutions; however, availability problems and our need for flexible experiments with different set-ups decided us to build our own prototype.

6 Conclusion

In this paper we have presented a case study aiming at solving the semantic interoperability problem in the context of CH resources, using automatic alignment processes between their vocabularies.

This study provided interesting insights regarding the use of SW techniques in a CH environment. We have seen that the conversion of vocabularies using standardised formats is possible, and helps their deployment. We have also shown that based on such representation and automatically found mappings, an operational interface for browsing heterogenous collections in an integrated way *can* be implemented.

If all collections and thesauri were available in standard formats (SKOS, RDF) or when automatic conversion is feasible so that translation steps would not be needed anymore, our framework would provide a very easy way of integrating heterogeneous collections. However, there still are problems to solve before this ideal situation occurs:

- we have to overcome the loss of semantics when translating the thesauri into SW standards for instance by providing more expressive standards,
- ontology mapping tools should be compliant with the SW standards concerning input and output formats, and
- specifically for CH controlled vocabularies, it would be preferable to have a SKOS standard inference engine instead of an RDF(S) one. [14]

Furthermore, all tools (mappers, inference engines) should be scalable for handling the enormous amount of data present in CH.

Concerning the use of ontology mappers for our CH case, we learned that available ontology alignment techniques need to be tuned to be of use for e.g. thesaurus mapping. Most mappers use resources that are absent from thesauri, e.g. properties, and refrain from (properly) using all information found in thesauri, e.g. synonyms. S-Match mapping quality (46%) is a lot higher than Falcon

[14] Note the discrepancy between this point and the first; the use of standards limits the amount of transferable information, but provides generalizability.

one (16%), but must still be improved to be useful for browsing purposes. Typical features such as gloss descriptions and poor structuring should be taken into account when constructing a thesaurus mapper. Additionally, manual thesaurus mapping is heavily labour-intensive and ambiguous. So, to perform semantic integration of CH collections the way we envision, automated mapping techniques are absolutely indispensable.

Finally, our interpretation of Multi-Faceted Browsing provides multiple views or access points for a same set of data. This way users can choose the vocabulary they are most comfortable with and thus personalised access is granted. We encourage the reader to try this browser online:
`http://stitch.cs.vu.nl/demo.html`.

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References

1. Giunchiglia, F., Shvaiko, P., and Yatskevich, M.: Semantic Schema Matching 13th International Conference on Cooperative Information Systems (CoopIS 2005).
2. Hearst, M., English, J., Sinha, R., Swearingen, K. and Yee, P.: Finding the Flow in Web Site Search. Communications of the ACM, 45 (9), 2002.
3. van Assem, M., Menken, M. R., Schreiber, G. et al.: A Method for Converting Thesauri to RDF/OWL. Int. Semantic Web Conference, Hiroshima, Japan, 2004.
4. Clavel-Merrin, G.: MACS (Multilingual access to subjects): A Virtual Authority File across Languages. Cataloguing and Classification Quarterly 39 (1/2),2004.
5. Constantopoulos, P., Sintichakis, M.: A Method for Monolingual Thesauri Merging. ACM SIGIR Conference, Philadelphia, USA, 1997.
6. Doerr, M.: Semantic Problems of Thesaurus Mapping. Journal of Digital Information, 1 (8), 2004.
7. Hyvönen, E., Mäkelä, E., Salminen, M., Valo, A., Viljanen, K. et al.: MuseumFinland - Finnish Museums on the Semantic Web. Journal of Web Semantics, 3(2), 2005.
8. Kalfoglou, Y., Schorlemmer, M.: Ontology Mapping: The State of the Art. The Knowledge Engineering Review Journal, 18(1), 2003.
9. Gasevic, D., Hatala, M.: Searching Web Resources Using Ontology Mapping. K-CAP Workshop on Integrating Ontologies, Banff, Canada, 2005.
10. Jian, N., Hu, W., Cheng, G., and Qu, Y.: Falcon-AO: Aligning Ontologies with Falcon. K-CAP Workshop on Integrating Ontologies, Banff, Canada, 2005.