Combining three Ways of Conveying Knowledge: Modularization of Domain, Terminological, and Linguistic Knowledge in Ontologies

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Abstract. Recently, an overall trend towards increasing complexity of ontologies could be observed, not only in terms of domain modeling, where the complexity should correspond to the information to be modeled, but also as regards the addition of further information, which could be modeled as external resources to the domain model and linked to its relevant elements. This concerns the addition of terminological and linguistic information to the description of classes and properties of ontologies. To respond to this development, we propose a functional approach to the modularization of ontologies, based on terminological, linguistic, and conceptual functions each module fulfills. Only the conceptual elements and their structural properties should remain in the domain model, whereas the formalized terminology and linguistics are described in independent modules referencing the domain models. We provide examples of such complexity in Knowledge Representation systems, discuss related work, and present our approach to modularization in detail.

Keywords: ontology, terminology, linguistics, lexicon, LabelNet, SKOS, TBX, TMF, lemon

1 Introduction

Nowadays, ontologies in general not only contain domain knowledge but further information central to various tasks of ontology-based systems. For instance, terminological and linguistic details are substantially different in nature from the former and usually encoded in labels adjoined to IDs of classes and properties.

There is a growing realization among many researchers that it might not be the best practice to encapsulate such information within the description of classes and properties of domain ontologies. Proposals have already been made for the separation of terminology and lexicon from domain ontologies and for strategies on the linking of this information to the elements of the domain model in a more principled way [1–6]. Our approach to modularization can be considered functional, as it is based on the functions the terminological and linguistic elements used in the context of domain models fulfill. Several tasks such as supporting Information Systems (IS), semantic annotation, lexicographic applications, translation, localization among many others benefit from encapsulated and reusable functions as presented herein.

The need to cull content of labels in ontologies has increased with more possibilities to linguistically process labels, adding linguistic annotations to their textual content and thereby more complexity to the ontology. As a result, reusability and sharing of the information accumulated is considerably impeded since navigation through the entire ontology is required in order to find linguistically annotated terms that are relevant to ontology-driven applications.

Therefore, following a series of similar proposals [1–3], extending and specifying some points made, we suggest a strict modularization of domain ontologies in a class hierarchy, a terminology, and a linguistic component, all represented in RDF/OWL and related to each other by means of the Simple Knowledge Organization Scheme of the W3C (SKOS) and similar linking mechanisms. Thus, a lexical entry can be used by several terminologies, terms of which are employed in different specific ontologies.

The proposed model largely facilitates the detection of interrelations among ontologies, rendering the formation of new ontologies on the basis of existing independently built ones faster and less complicated, because the model strips ontologies to their core and most essential elements. It equally aims at more compact terminologies and lexicons used in relation with domain modeling, since variants of these can be more easily detected and collapsed onto harmonized sets. Thus, our three-module system represents a mechanism for increasing flexibility in reusing ontologies as well as domain-specific lexicons and terminologies.

2 Steadily Growing Complexity of Ontologies

A class defined in the RadLex ontology[3] serves to exemplify the growing complexity in ontologies. As can be seen in the example below, the class RID 13218 contains all information about its superordinate class and the related properties. Furthermore, information on natural language expressions associated with the class (*synonym, NonEnglish_Name, Preferred_Name, ORIG_Preferred_Name, Definition*) as well as other knowledge sources, i.e., FMAID 67112, were accumulated to form one single ontology class. The knowledge source refers to the Foundational Model of Anatomy (FMA)[4]. Upon looking at the entry in the FMA ontology, it can quickly be inferred that elements have just been duplicated, such as the definition, synonym, the (German) Non-English part and the label (preferred name).

[3] Version 3, http://bioportal.bioontology.org/ontologies/2027?p=terms

[4] The URL for the indicated ID is `http://bioportal.bioontology.org/ontologies/44507/?p=terms&conceptid=fma\%3AImmaterial_anatomical_entity`

```
<class>
          <name>RID13218</name>
          <type>anatomy_metaclass</type>
          <own_slot_value>
                 <slot_reference>FMAID</slot_reference>
                 <value value_type="string">67112</value>
          </own_slot_value>
          <own_slot_value>
                 <slot_reference>Synonym</slot_reference>
                 <value value_type="string">immaterial physical anatomical
                 entity</value>
          </own_slot_value>
          <own_slot_value>
                 <slot_reference>Non-English_name</slot_reference>
                 <value value_type="string">immaterielles körperliches
                 anatomisches Wesen</value>
          </own_slot_value>
          <own_slot_value>
                 <slot_reference>Preferred_name</slot_reference>
                 <value value_type="string">immaterial anatomical entity</value>
          </own_slot_value>
          <own_slot_value>
                 <slot_reference>ORIG_Preferred_Name</slot_reference>
                 <value value_type="string">immaterial anatomical entity</value>
          </own_slot_value>
          <own_slot_value>
                 <slot_reference>Definition</slot_reference>
                 <value value_type="string">Physical anatomical entity which is a
                 three-dimensional space, surface, line or point associated with a
                 material anatomical entity. Examples: body space, surface of heart,
                 costal margin, apex of right lung, anterior compartment of
                 right arm.</value>
          </own_slot_value>
          <own_slot_value>
                 <slot_reference>Is_A</slot_reference>
             4     <value value_type="class">RID13441</value>
          </own_slot_value>
          <own_slot_value>
                 <slot_reference>Has_Subtype</slot_reference>
                 <value value_type="class">RID13221</value>
                 <value value_type="class">RID13250</value>
                 <value value_type="class">RID13291</value>
                 <value value_type="class">RID13307</value>
                 <value value_type="class">RID15845</value>
                 <value value_type="class">RID13217</value>
          </own_slot_value>
          <own_slot_value>
                 <slot_reference>:ROLE</slot_reference>
                 <value value_type="string">Concrete</value>
          </own_slot_value>
          <superclass>RID13441</superclass>
</class>
```


[Example of growing complexity in ontologies by means of a RadLex class.]

It seems that the RadLex ontology in this particular case reuses many elements of FMA, as the focus of RadLex is rather on phenomena that can be observed in correlation with specific organs and not the organs themselves. While this integration of terminological and linguistic knowledge in the field of anatomy is obviously a good move, re-using established terminology, it appears that it could be more beneficial to provide this pool of information independently from the ontologies modeling the domain. Clear links between the original ontology and terms used as well as linguistic data substantially improve the level of re-usability and readability of semi-structured or definitional natural language expressions across a large number of ontologies (or taxonomies).

3 Related Models

Several approaches and models emphasize the importance of separating conceptual, terminological, and lexical information. Some concentrate on the terminological aspect [6, 9], while others focus on the lexical aspect [10, 4]. Buitelaar et al. [10] propose a model called *LexInfo* and suggest adding lexical, morpho-syntactic, and chunking information to the labels of ontology classes. The authors design an OWL representation scheme for this set of linguistic information and its linking to ontology classes. *LexInfo* supports in this among other aspects the ontology-based semantic annotation of text.

The *Terminae* [5] model suggests having two distinct, but interlinked high levels of classes within ontologies: one for the hierarchy of concepts (and associated relations), and one for (a list of) terms that point to the concepts they denote. Thus, the concept level world gets cleaner and, for example, the very cumbersome manner of encoding synonyms and other related terms as it is done in RadLex (see RadLex example above) can be avoided, since synonyms are encoded on the terminological level of the ontology. One major advantage of this approach is that a subset of a terminology can more easily be identified and re-used in other (domain) ontologies. Reymont et al. [9] provide an example of the application of *Terminae* in the automotive domain. We note that in *Terminae* the lemma and part-of-speech information is encoded within the term classes.

A third approach, suggesting the merging of *LexInfo* and *Terminae* is CTL [2]. CTL applies the full model of *LexInfo* to each word in a term. Thereby it completely takes lexical information out of the descriptions of both domain and term classes. This leads to three layers of description within the ontology, where a meta-class has three main subclasses describing domain-class, terminology, and linguistic hierarchies. The linguistic layer is based on and extends *LexInfo*. However, CTL neither proposed a formalization nor an implementation, but instead generally described such an approach. Both Terminae and CTL accumulate the different modules (meta-classes) in one ontology, which supports an internal view on the interaction between them, rendering linking of terms to other ontologies more difficult.

Some approaches emphasize the added benefit of a combination of all three modules for specific tasks (e.g. [7]). Bodenreider [7] makes use of existing terminologies, ontologies, and lexicons for text mining in biomedicine. The emphasis here is on already existing not perfectly compatible resources and the specific task of text mining.

All approaches above agree that natural language processing and subsequent linguistic annotation of the terms used in labels are necessary. In order to ensure interoperability and re-usability, we use standardized models. The Terminological Markup Framework (TMF), defined in ISO 16642, ensures the re-usability of terminological data across applications and the TermBase eXchange (TBX) format of ISO 30042 represents a best practice for the practical exchange of terminology. In line with ISO 704, we take a concept oriented approach towards terminology, defining terminology as concepts and their designations in a specific domain. Consequently, a term is a verbal designation denoting a general concept in a specific domain. The *lemon* model [4] we discuss below proposes a way to obtain the results of natural language processing and annotation in a modular RDF representation.

4 Modularization of Ontology Labels

We propose LabelNet, a model that modularizes each lexical, linguistic, and terminological function related to ontology labels, establishing a net of interlinked terms with highly detailed information at each level. Term entries in a separate OWL-DL encoded TBX- and TMF-compliant terminology relate semantically to corresponding ontology classes or other conceptual elements and represent the terminological information in detail. Each token[5] of every term entry links to a lexical entry, i.e., to a lemma[6], syntactic information, and possible additional resources such as further ontologies. Fig. 1 exemplifies the structure of LabelNet and shows how each of its modules can be interlinked using SKOS. The example data has been taken from an ontology based on the Belgian National Bank (BNB) taxonomy. Time concepts are linked to the W3C time ontology, e.g., "more than one year" is an interval.

The lexical entries are represented by using partially the *lemon* model [4], which is described in the next section. The semantics of the list of tokens contained in a term is established by referring to the ontology elements on the basis of the term ID in the terminological entries.

By separating the several layers into modules we achieve a more complete and highly detailed perspective of ontology labels. The separation of lexical entries and terms into lexicons and terminologies provides a higher degree of re-usability. In addition, it facilitates a number of computations over these labels, such as the usage of a certain lemma in terms pointing to concepts/role IDs.

4.1 The *lemon* Model

lemon provides a model that can encode lexical information, using among others RDF, URIs and linking mechanisms, so that language data can be exchanged for example in the Linguistic Linked Open Data cloud[7]. The model aims at a strict separation of 'world knowledge' (describing domain objects that are

[5] Tokens can be defined as all meaningful elements in a text that result from the process of tokenization, i.e., breaking up text into words, phrases, symbols or other meaningful elements. The ordered collection box in Fig. 1 contains lists of tokens as they appear in the terms used in the exemplified labels.

[6] A lemma represents the canonical form of a set of words called lexemes. For example, *accrue* is the lemma of *accrued, accruing, accrues,* etc.

[7] http://linguistics.okfn.org/resources/llod/

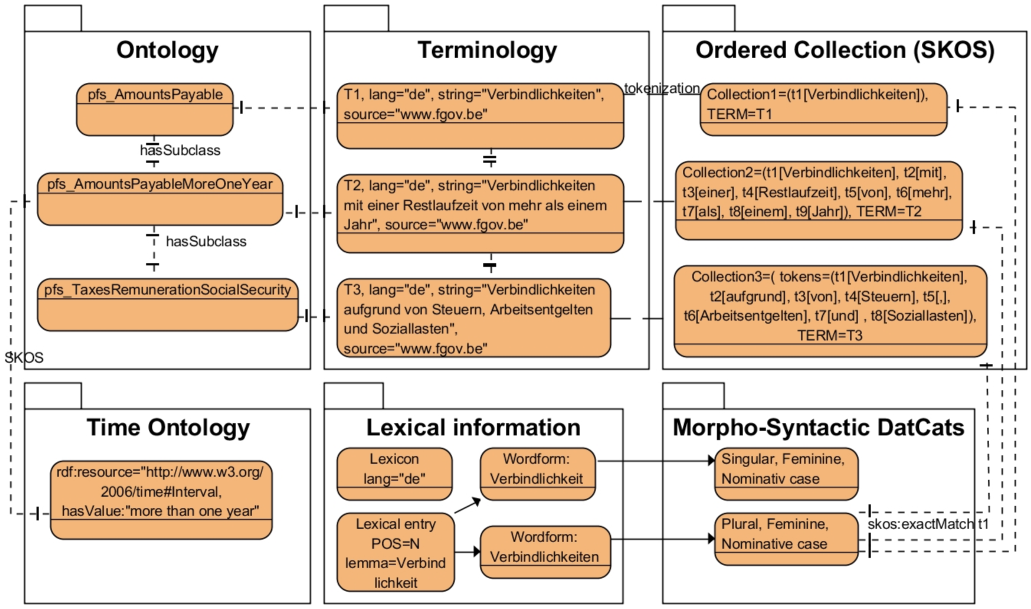

Fig. 1. Simplified example of LabelNet

referenced by lexical objects) from 'word knowledge' (describing lexical objects). It is itself modular, having a core component that can be supplemented with a set of modules to be used, extended, or ignored as required as illustrated in Fig. 2. For example, a morpho-syntactic module can be attached to the core, specifying specific values for words used in the term, such as gender (feminine, masculine, neuter), number (singular, plural, dual) and case (nominative, accusative, etc). As this model in essence enables the creation of a lexicon for a given ontology, it is called an ontology lexicon model. *lemon* as such does not provide an explicit terminological level and refers directly from the lexical entry (in *lemon* a lexical entry represents the whole content of a label) to an ontology element. In contrast, LabelNet stresses the need and the practicability of a terminological level, we re-use only the non-referential part of the *lemon* model.

4.2 Lexicon Module

While *lemon* offers a highly interesting perspective, we think that there are still some shortcomings, or possible improvements. A first case is the fact that lemon supports tokenization of terms included in labels, but not the establishment of the relation between a token represented as a standalone lexical information and the terms in which it can occur. Consequently, we propose an extension that allows for a single lemma to include the information that it is part of a term, in the position specified by the tokenization process. Thereby, the word "Verbindlichkeiten" (German for *amounts payable* or *liabilities*), for example,

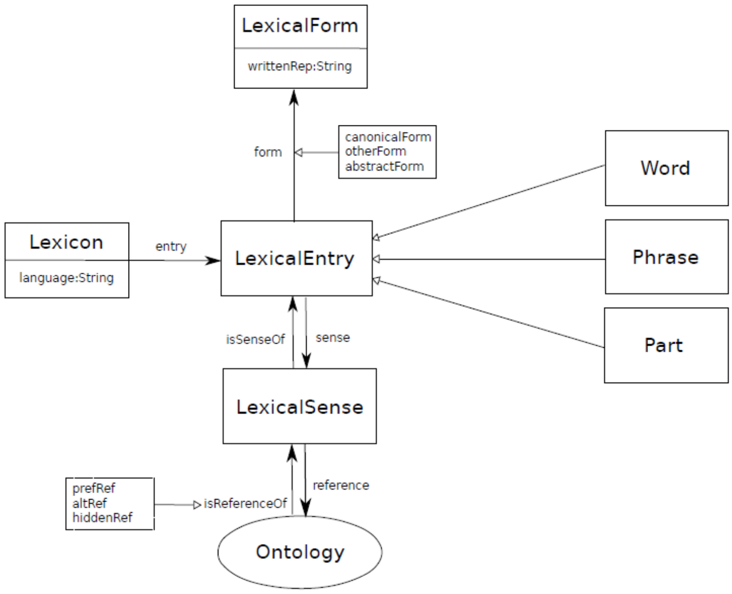

Fig. 2. Simplified representation of the lemon model [4]. The link between lexical and ontology information is established by the reference link

will be linked to a (possibly) substantial number of terms used in various domains (see Fig. 1). In doing so, we can generate a new kind of WordNet, taking into account the inclusion of relevant words in a category of terms. Adopting the idea of *lemon*, we model only lexical and linguistic information in this separate module, linking to semantic values on the basis of the term ID, which itself links to an ontology element.

As a matter of fact, *lemon* entries allow only one semantic reference. The *lemon* model represents the content of labels of one ontology at a time. But frequently one and the same term is used in different (even related) ontologies/taxonomies. In this case, two or more *lemon* entries would be required, leading to redundant lexical/linguistic information only differing in the entry point to elements of different ontologies. One entry pointing to many ontologies represents a more efficient approach. This would also ease generalization over the semantics of such terms.

In case different terms are used in concepts of different ontologies, but a `skos:exactMatch` can be established between these concepts, *lemon* does not provide the means to express the lexical semantic relationship between these terms. As a result, SKOS has to be used as a linking means between those concepts, thereby indirectly establishing the lexical semantic relationship, such as synonymy, between different terms.

Apart from linking different entries or elements of individual modules, certain constraints need to be reflected. For example, in German and English only the plural of "Verbindlichkeit/liability" might be used within the context of financial reporting. One possibility in *lemon* would be to select only terms in which the word "Verbindlichkeit" appears in its plural form "Verbindlichkeiten". Another possibility, which has our preference, would be to associate a feature structure with the lemma we have extracted from the tokens of the ontology labels, in which additional linguistic information can be encoded. Keeping thus the basic lexicon small, i.e., containing mainly lemmas, and using well-defined feature structures as labels for the edges going from one lemma to a more complex term containing the lemma. We suggest having the constraints expressed in SKOS, linking between a lemma and a term (see Fig. 1):

```
lemma:Verdbindlichkeit -> [plural, feminine, nominative case] -> t1(T3)
```

The above line expresses that only the plural and nominative form of "Verbindlichkeit", which is feminine, can be used in combination with a term (at least the term "T3"') related to a business reporting ontology.

4.3 Terminology in OWL-DL

Terminologies as such consist of terms denominating concepts, their definitions and concept relations. In case of SKOS, these elements are utilized towards building controlled vocabularies, whereas the TermBase eXchange (TBX) format of ISO TC 37 can be described as discourse-oriented terminology [8]. In controlled vocabularies, terms have to be classified as preferred, synonyms being mapped to preferred terms for retrieval purposes. In case of the discourse-related resources, many synonyms are permitted and the attribute "preferred" can be assigned for a prescriptive usage. Wright et al. [8] state that terminologies always relate to special language, "designating multiple preferred terms subject to multiple pragmatic constraints". Thus, the former differs from the latter in that it represents varying conceptual information and semantics with a focus on information retrieval, whereas discourse-oriented terminological resources are more adequate for the purpose at hand.

In our model the terminology is supposed to be reusable for other tasks such as translation, ontology population, ontology building, ontology evolution to name but a few. Instead of using status attributes such as preferred, alternative, and hidden, TBX allows for the use of subset information such as project, application, customer to clarify the difference between synonyms [8].

Terminologies provide greater multiplicity than only `rdfs:labels`. Terms and natural language information acquired for and within the process of ontology building are often lost in the final representation due to a required univocity of each label. Constructing a net of ontology labels and their synonyms acquired in the building of ontologies and extraction of information results in a domain-specific, formalized, and reusable resource for ontologies.

Another reason for transferring natural language information from the ontology to terminologies can be found in its ability to represent conceptual relations different from ontological relations and thus, enhance the representation of information with linguistic details. For example, a financial reporting ontology classifies *liquid assets* as sibling of *key balance sheet figures*, the latter of which being the parent to *assets*. In contrast, hypernymic relations in the terminology see *assets* as top node, whereas *liquid assets* is one of its children.

TBX is an XML-encoded markup language for the interchange of terminological information. Due to reasons of cardinality and variation its transformation to RDF, i.e., SKOS, turns out to be difficult as described in detail in [8]. Instead of mapping TBX to RDF a member of the OWL family of languages is more adequate to the task. The cardinality of OWL-Lite, however, is restricted to 0 and 1, which in case of many term entries might constitute a problem to be solved with OWL-DL and its ability to allow arbitrary values for cardinality. All core elements of the terminology are children of the top node `owl:datcat` to signify that all subclasses are data categories and interlinked by means of properties such as `unionOf` and `owl:equivalentClass`. A detailed description of rendering TBX in OWL-DL would go beyond the scope of this paper, a representation of terminology in OWL-DL is to be found in [6].

4.4 Step by Step to Modularized Ontologies

Our architectural decisions and selections have been described above, but the specification of the process of obtaining each resource and achieving modularization has yet to be detailed. The main input to building the initial ontology is financial information, such as annual reports of companies, reporting standards (e.g. IFRS, GAAP, XBRL, etc.), stock exchange websites. We extract details from the named sources and build an initial ontology. Furthermore, the extracted information represents the input for the terminology, where all synonyms are depicted. On the basis of the ontology and the terminology, the lexicon is established. So at the core of the following steps lies the formalization of the extracted knowledge in a domain ontology representing our input.

1. Extract labels/terms and linguistic analysis of terms (tokenization, lemmatization, morphological analysis, tagging, parsing, etc).
2. Extract all lemmas, create or map to an existing lemma in a (multilingual) lexicon to collect all lemmas that are used in all possible labels of all possible ontologies.
3. Encode lemmas in *lemon*. Add a data structure on top of each lemma, which lists all the tokens in all labels in which the lemma is reproduced. This linking also reflects the morpho-syntactic features of the token according to its analysis.
4. Record all morpho-syntactic and lexico-syntactic information and patterns in the corresponding addition to the linguistic module.
5. All identical labels are stored as a unique element in a terminology container. Specify term entries as to their conceptual relations and establish proper definitions or adapt definitions existing in the ontology.

6. Each *lemon* represented term is associated with a data structure, i.e., terminology, that points to a variety of ontology elements in which those terms have been introduced.
7. Eliminate all the labels and other linguistic information from the ontology, flattening class entries to domain specific details.

As a result, we have two interlinked ontologies of lemmas and terms as used in ontologies/taxonomies. Thereby, we obtain a subset of language data, which is used in domain ontologies. This can be used in order to analyze textual documents and to annotate them semantically, populate ontologies, or support translations with semantics to name but a few. On the other hand, we have a means for testing ontology mapping or merging.

5 Linking all Modules

The main linking device between ontologies is SKOS, such as the linking between the financial reporting ontology and the time ontology in the example provided in Fig. 1. Especially with multilingual ontologies the individual concepts and their matching by means of SKOS is important. Oftentimes, the pivotal role of English as a source language leads to translations of labels instead of proper localizations. In case of financial reporting standards it is indispensable to take local legal and political regulations affecting the standard into consideration, as the Belgian reporting standard in French might differ substantially from the reporting standard used in France, especially in the use and interpretation of applied French terms.

By conceptualizing the knowledge in each language individually, the ontology is actually created in each language and not simply translated. Thereby, we are in the position of linking for example the English concept `pfs_AmountsPayableMoreOneYear` to the corresponding Italian concept `itcc-ci_DebitiEsigibiliOltreEsercizioSuccessivo` by employing `skos:exactMatch`, which implicitly links the term "Debiti Esigibili Oltre l'Esercizio Successivo" to the English term. For existing monolingual ontologies this proposal might serve as a method for merging several monolingual ontologies by establishing links.

The domain ontology represents the starting point for the linking, containing the initial SKOS links to the terminology, as the terminology might be treated as ontology represented in OWL-DL. From the terminology references to the lexicon holding all individual lemmas can be established. At the same time the terminology represents the interface to lexico- and morpho-syntactic patterns as well as syntactical information as such and all tokens, the result from the process of tokenization.

One part of the linking process is the representation of lexico- and morpho-syntactic patterns and information to support the evolution and extension of existing domain ontologies. Thereby, the construction of new labels is largely facilitated on the basis of the structure of existing labels.

Syntactic information is represented by combining tokens and dependency information of individual terms. Basically, syntactic categories are determined on the basis of part of speech tagging and phrasal categories are used for syntactic labels. For example N-NP = (length=1, token[1]=N, head=token[1]) represents the term "Verbindlichkeiten", which has the syntactic category "Noun" and the phrasal category "Noun Phrase" with a length of one and token1. For the purpose of standardization, these categories are mainly taken from the ISOcat database[8].

Especially for information extraction in combination with ontology evolution the representation of lexico-syntactic patterns is essential, such as lexico-syntactic ontology design patterns[9] and the famous Hearst patterns. One example for their use is the recognition of relations among entities during information extraction. The following sentence has been taken from the International Financial Reporting Standard (IFRS): "The statement of financial position (sometimes called the balance sheet) includes an entity's assets, liabilities and equity as of the end of the reporting period"[10]. The lexico-syntactic equivalence `<NP class>` call in passive `<NP class>` relation between "statement of financial position" and "balance sheet" enables us to realize that both terms point to the same ontology concept as synonyms, however, including a description of their difference in the definition of the terminology. The Hearst pattern `[NP0] [VBG include] [NP1] [NP2]...` indicates that "assets, liabilities and equity" can be modeled as `subClassOf` "statement of financial position".

6 Conclusion and Future Directions

Modular and encapsulated domain, linguistic, and lexical functions for knowledge modeling enable the support of several IS-related as well as Natural Language Processing (NLP)-driven tasks. Each modularized resource, i.e., ontology, terminology, or lexical information, can either be used as part of the interlinked model we presented or as individual resource for other purposes. One aspect for further improvement certainly is the linking device between the modules, which could be optimized towards an enhanced interoperability with other systems and among the resources themselves.

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[8] http://www.isocat.org/

[9] http://ontologydesignpatterns.org/wiki/Submissions:LexicoSyntacticODPs

[10] http://www.ifrs.org/Home.htm

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