Making Ontology Relationships Explicit in a Ontology Network

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Abstract. The development of ontologies to the Semantic Web is based on the integration of existing ontologies favoring the modularization and reuse of them. These ontologies are used together in complex applications. However, how they are combined is usually hidden in the application code. The lack of an approach for explicitly expressing the way how ontologies are combined for a specific purpose, leads to think on ontology networks as a new ontology engineering concept. This paper formally defines the different relationships among the networked ontologies and shows how they can be modeled as an ontology network in a case study of the health domain.
Keywords: ontology network, ontology relationships formalization, quality assessment.

1 Introduction

Tom Gruber [1] has defined "ontology" as a "formal, explicit specification of a shared conceptualization", what means that ontologies are very useful for structuring and defining the meaning of the metadata terms that are collected inside a domain community.

Nowadays, autonomously developed ontologies emerge quite naturally in different domains (health, tourism, learning, quality of services, etc.). These ontologies, each one built for different purpose, are used together in complex applications. However, how they are combined is usually hidden in the application code, without explicitly expressing the way how ontologies are combined for a specific purpose. This situation leads to think on *ontology networks* as a new ontology engineering concept, which is being increasingly applied, instead of custom-building new ontologies from scratch. An ontology network differs from a set of interconnected single ontologies, due to in it the meta-relationships among the different ontologies involved are explicitly expressed [2]. As part of the NeOn methodology [3], different scenarios for building ontology networks were identified, ranging from the construction of an ontology network from scratch up to the reuse of ontological and non-ontological resources.

The main contribution of this paper is a first definition, based on the Description Logics formalism, of the different relationships among networked ontologies. Our work attempts to assuring the consistency of the ontology network specification.

The remainder of this paper is organized as follows. Section 2 gives an overview of ontology-network and the theoretical background of this work. Section 3 introduces the ontology relationship definitions. Section 4 briefly describes a case study in the health domain, more specifically a recommendation system. Section 5 details the modelling of an ontology network, applying the specified ontology relationships among the ontologies of the case study. Finally, Section 6 gives some conclusions and future works.

2 Background

An *ontology network* can be defined as a collection of ontologies related together through a variety of different relationships such as mapping, modularization, and versioning, among others [4]. Distributed and collaborative methodologies of ontology design, such as DILIGENT [5] and the NeOn project approach [2], allows the design of local models based on a core model which integrates the local ones.

Intuitively, defining an ontology network is to select a set of networked ontologies, by identifying the different kinds of relationships between the networked ontologies. There are some models that cover both the syntactic aspects of ontology relationships and the semantic aspects of interpreting ontology networks and their relations. For instance, the Collaborative Ontology Design Ontology (C-ODO) [6] is an ontology network that describes design entities (ontologies, modules, activities, etc.). In [4], Allocca et al. present general relations between ontologies, such as *includedIn*, *equivalentTo*, *similarTo* and *versioning*, describing them in the DOOR (Descriptive Ontology of Ontology Relations) ontology. Grau et al [7] propose a work that adapts important notions of software engineering, such as *module* and *black-box behavior*, to be applied in the reuse and integration of ontologies. In [8], Zimmermann et al. introduce the concept of *Distributed System* as a set of ontologies interconnected by ontology alignments, describing semantic relations between ontologies, such as: *cross-ontology concept subsumption* or *cross-ontology role subsumption*, among others.

There also exist several works that propose formal definitions of the *ontology mapping* (or ontology alignment) concept, such as [9–12]. Most of them formalize the idea of *mapping* between concepts, relations and instances (so called *entities* by [12]) of two ontologies. They also address the problem of finding these correspondences between entities of different ontologies. But in the real world, we find other ontology relationships beyond mapping, that is, it is not always the case that two ontologies are related through an alignment between concepts, relations or instances. Except for the works [4] and [10], which defines *bridge axioms* to express different relationships between ontologies in a general way, these proposals do not address a formalization which explicitly states the possible different relationships between two ontologies. Our approach is similar to [4] because it defines ontology relationships. But our proposal differs from [4] in two main aspects:

- DOOR's relationships were extended by adding the *usesSymbolsOf* relationship.
- Our work is an introduction of a formalization of the inter-ontology relationships.

3 Ontology Relationships in a Ontology Network

Based on the NeOn Methodology [13], we have analized how to perform the combination of different types of knowledge resources for building an ontology network, formalizing a selected set of *ontology relationships*. This set of relationships allowed us to design an ontology network, expressing explicitly the semantics of the relationships in a particular set of ontologies. This paper is a first intend of formalization towards the obtaining of a complete and minimal set of ontology relationships necessary and sufficient to build an ontology network.

We have considered four ontology relationships: *isTheSchemaFor*, *isAConservativeExtentionOf* and *mappingSimilarTo*, taken from the DOOR ontology and one relationship named *usesSymbolsOf*, identified in the present work. Below we present a conceptual and a formal definition of each relationship. These definitions are based on the *Description Logics* formalism (DLs) [14–16], applying the concepts: *Signature* of a DL [7, 17], *concept description*, *concept definition*, *general concept inclusions* (GCIs), *TBox* [14, 16], *interpretation* [16, 17], *ABox* [16], *consistency of an ABox w.r.t. a TBox* [16], *model of an ontology* [7] and *logical consequence of an ontology* [7].

To introduce the ontology relationship definition we assume we have two ontologies O and O' formalized by a DL $\mathcal{L}$, formally represented by $(\mathcal{T}, \mathcal{A}, \mathcal{I}, N)$ and $(\mathcal{T}', \mathcal{A}', \mathcal{I}', N')$ respectively, where:

$\mathcal{T}$ and $\mathcal{T}'$ are the TBox,
$\mathcal{A}$ and $\mathcal{A}'$ are the ABox consistent w.r.t. $\mathcal{T}$ and $\mathcal{T}'$, for the models $\mathcal{I} = (\Delta^I, \cdot^I)$ and $\mathcal{I}' = (\Delta^{I'}, \cdot^{I'})$ respectively,
N and N' are the sets of individual names of the domains Δ^I and $\Delta^{I'}$ respectively.

***isTheSchemaFor* relationship**

Conceptually, this relationship keeps the link between a model and its metamodel. A formal definition is:

Let O and O' be two ontologies.
Let $G = \{C_i{}' \mid C_i{}' \in \mathcal{T}'$ is a concept description$\}$, $R = \{r_i{}' \mid r_i{}' \in \mathcal{T}'$ is a role name$\}$, $G^{I'} = \{{C_i{}'}^{I'} \mid {C_i{}'}^{I'} \subseteq \Delta^{I'}\}$, $R^{I'} = \{{r_i{}'}^{I'} \mid {r_i{}'}^{I'} \subseteq \Delta^{I'} \times \Delta^{I'}\}$
O is the Schema for O' (isTheSchemaFor(O, O')) if there exists:

- a function $s : \mathcal{A} \to G \cup R$ that maps each concept assertion $C(i)$ to a concept description ${C_i}'$ or a role name ${r_i}'$ and
- a function $s_I : \Delta^I \to G^{I'} \cup R^{I'}$ that maps each domain element i^I to the set ${C_i}'^{I'}$ or to the binary relation ${r_i}'^{I'}$, where:

$C \in \mathcal{T}$ is a concept description, $i \in N$, $C(i) \in \mathcal{A}$, $i^I \in C^I$ since $\mathcal{A}$ is consistent w.r.t. $\mathcal{T}$ for the model $\mathcal{I}$, ${C_i}' \in \mathcal{T}'$, ${r_i}' \in \mathcal{T}'$

***isAConservativeExtensionOf* relationship**

This relation describes an extension of a given ontology by a number of additional axioms, which describe what has not been covered yet by the existing ontology. Formally:

Let O and $O' \subseteq O$ be two ontologies.
Let $sig(O')$ be the signature of O' over $\mathcal{L}$;
O is a Conservative Extension of O' (isAConservativeExtensionOf(O, O')) w.r.t. $\mathcal{L}$ if for every axiom α over $\mathcal{L}$ with $sig(\alpha) \subseteq sig(O')$, we have $O \models \alpha$ iff $O' \models \alpha$ [7, 17].

***mappingSimilarTo* relationship**

An ontology O *isSimilarMappingTo* an ontology O' if there exists an alignment from O to O' and this alignment covers a part of the vocabulary of O. The formal definition is:

Let O and O' be two ontologies.
Let $K \subseteq \{C \mid C \in \mathcal{T}$ is a concept description$\}$, $K' \subseteq \{C' \mid C' \in \mathcal{T}'$ is a concept description$\}$, $K^I = \{C^I \subseteq \Delta^I \mid C \in K\}$, ${K'}^{I'} = \{{C'}^{I'} \subseteq \Delta^{I'} \mid C' \in K'\}$
O is Mapping Similar to O' (isMappingSimilarTo(emphO, O')) if there exists:

- a function $m : K \to K'$ that maps each concept description $C \in K$ to a concept description $C' \in K'$ and
- ${K'}^{I'} \subseteq K^I$, that means the subset $K^I \subseteq \Delta^I$, in the model $\mathcal{I}$ for the ontology O, includes the set ${K'}^{I'} \subseteq \Delta^{I'}$ of individuals in the model $\mathcal{I}'$, for the ABox $\mathcal{A}'$ in the ontology O', that asserts the concepts of the set K' which are mapped to the concepts of the set K by the function m.

This definifion is based on the concepts of morphism [9], ontology alignment [10], mapping function [11], mapping source and target ontologies [18] and ontology alignment function [12].

***usesSymbolsOf* relationship**

The *usesSymbolsOf* relationship happens when the properties at an ontology O involves individuals from another ontology O', in such a way that the ontology O defines some properties that take value in individuals that are classified by classes of the ontology O'. The *usesSymbolsOf* relationship links ontologies

O and O' in such a way that it abstracts from the particular ontology O' to be imported and focuses instead on the symbols from O' that are to be reused. Previously to introduce the definition of the *usesSymbolsOf* relationship, it is necessary to define the *safety of an ontology for a signature*:

Let O and O' be two ontologies.
Let S a signature over $\mathcal{L}$.
We say that O *is safe for* S *w.r.t.* $\mathcal{L}$, if for every ontology O' with $Sig(O) \cap Sig(O') \subseteq S$, we have that O is a conservative extension of O' w.r.t. $\mathcal{L}$ [7].

Now, we can introduce a formal definition of the *usesSymbolsOf* relationship:

Let O and O' be two ontologies with $Sig(O)$ and $Sig(O')$ over $\mathcal{L}$ and $Sig(O) \cap Sig(O') \subseteq Sig(O')$.
O uses Symbols of $\boldsymbol{O'}$ (usesSymbolsOf(emphO, O')) if O is safe for $Sig(O')$.

In the next section, we will introduce a case study of a recommender information system in the health domain. This case study will help to identify the different domain ontologies and how they must be combined in order to obtain the underlying model of this application. For this case study, the set of ontology relationships previously formalized was enough to explicitly express the links among the different domain ontologies.

4 A Case Study: Modelling a Health Information Recommender System

The use of the web as a knowledge repository where common people can find information, especially in the health area, increases drastically day by day. This is a very worrying reality because many of health websites do not contain data of good quality: precise, believable and relevant to user's profile. In this sense, a decentralized, intelligent recommender system can automatically give an evaluation about the quality of the sources according to the consumer's needs. Apart of the quality data issue, it is necessary to consider other aspects related to the context in which the user makes the query, like query goals and relevance feedback. All these issues lead to shape our health recommender system as based on quality assurance and context features, to give a reading recommendation of health resources for a particular user. Our approach involves several knowledge domains that have to be modeled and integrated as whole. These knowledge domains are *health* domain, *website* domain, *quality assurance* domain, *context* domain and *recommendation* domain. Below We will describe these knowledge domains, being each domain independent from each other, favouring the reuse of models. Particularly, in this paper we conceptualize each domain as an independent ontology as it will discuss in Section 5.

The ***Health Domain*** refers to terminology about health topics. It models for example the treatment, risk factors, diagnostic and effects of a disease. These concepts can be refined in terms of a specific disease i.e Alzheimer, and thus can be modeled the concepts Alzheimer Treatment or Alzheimer Diagnostic.

The ***WebSite Domain*** conceptualize the domain of webpages and particularly describe their contents. The main concepts are: *web content*, *web page* and *web site*, which can be characterized by other concepts such as *source* and *author*, depending on the application environment based on the Web Site domain.

Regarding the ***Quality Assurance Domain***, there exists a scientific approach that defines data quality dimensions rigorously, as dimensions that can be intrinsic or not intrinsic to an information system [19]. Some intrinsic data quality dimensions are: believability, accuracy and objectivity. Eysenbach et al. [20] present a study of how quality on the Web is evaluated in practice, comparing different methodologies of quality assessment.A domain expert must decide which dimensions are relevant for a specific domain and must define *metrics* in order to measure them. Then, the *Quality Assurance Domain* conceptualize metrics, quality assurance specifications and quality assessments. *Metrics* are formulas defined based on the properties of resources. For example, a metric can measure if a web page has an author, or count its number of words, etc. A *quality assurance specification* describes the different *quality dimensions*; for instance, readability, precision or believability. In order to make a quality assessment, one or more suitable metrics must be applied. For example a metric to evaluate the believability dimension of a web resource can be based on the resource's author. A *quality assessment* models the evaluation of a particular web content (i.e. a web page about Alzheimer) for a particular quality dimension through a specific metric. It is obtained a quality level, which represents the result of the quality assessment, for example, "high" or "low" believability.

The ***Context Domain*** describes user profiles, query situations and user actions. The user profile features user properties, such as age range or role (for instance patient or relative). The query situation models the concept of *query goal*, that is, explicitly ask users about their goal for each specific query in order to aid in the recommendation process. This can be done at two levels: *type of query*, which represents the possible intentions of a user when makes a query (informational, navigational or transactional) or *topic*, which is the issue of the query, for example Alzheimer. The user action represents the action of the user when makes a query for a specific task. Once the system had presented the user with an initial set of documents, the user can usually indicate those documents that contain useful information, giving his/her *relevance feedback*, which will be used as input to produce a reading recommendation of a content.

The ***Recommendation Domain*** describes the reading recommendation of a resource for a user. It models two aspects: the *recommendation specification* and the *recommendation* itself. The former specifies the recommendation definition, which describes the criterion upon which it relies to make a recommendation (i.e, a quality dimension), the context aspects and the possible recommendation levels. The *recommendation* models concrete recommendation assessments, based on a recommendation specification.

5 Making Explicit Ontology Relationships in a Ontology Network: a Case Study

In this section we explain how to build an ontology network, applying the ontology relationships defined in Section 3, for linking a set of ontologies that conceptualize the different and independent knowledge domains corresponding to the recommender system case study described in Section 4. More precisely, this ontology network is a network of ontology networks; this means that each knowledge domain involved is itself an ontology network and all of them are related among each other. Figure 1 outlines this approach; the different ontology networks are arranged by columns and the relation inter-ontology networks are shown by arrows crossing columns. In Section 5.1 the ontology relationships will be used to describe the specific-domain ontology networks and in Section 5.2 the ontology network is shaped as a network of ontology networks.

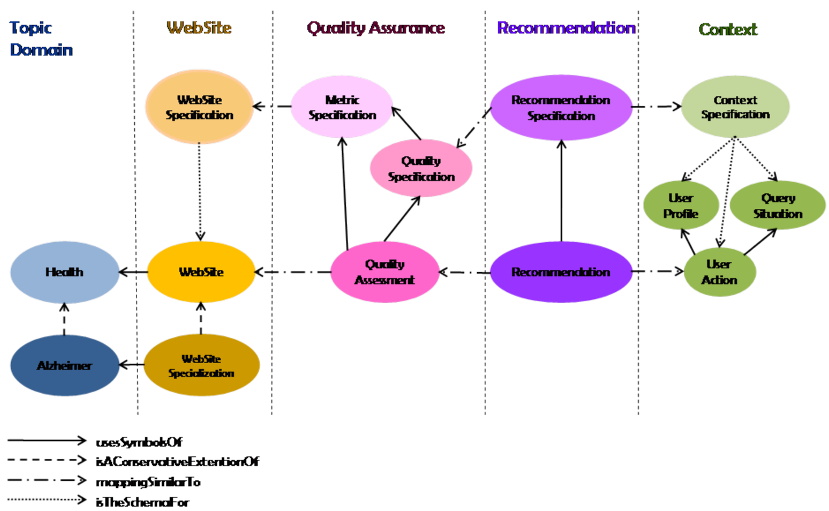

Fig. 1. The Health Ontology Network

5.1 Development of the Domain Ontology Networks

This section describes some of the different specific-domain ontology networks, designed by using the relationships between ontologies introduced above.

Health Domain ontology network comprises the *Health* and the *Specific Health* ontologies. The former conceptualize any diseases, while the last one is more specific, for instance the *Alzheimer* ontology.

Both ontologies are related by the *isAConservativeExtentionOf* relationship. The *Alzheimer* ontology isAConservativeExtentionOf the *Health* ontology, since, for instance, the concept *Treatment* of the *Health* ontology is extended by subsumption by the concept *AlzheimerTreatment* of the *Alzheimer*. This relationship is applied because in the health domain, there are some concepts that are general for all diseases (Diagnostic, Treatment), which can be reused in the knowledge base for a specific disease, such as alzheimer. Thus, this is the case where the knowledge expressed in the more generic *Health* ontology must be entirely reused in the more specialized *Alzheimer* ontology. Looking at the definition of *isAConservativeExtentionOf* relationship, the *Health* ontology should not be compromised by the new axioms. In particular, the extended ontology should not entail new subsumptions between concepts that are in the original one.

WebSite ontology network is composed by three ontologies: *WebSite Specification*, *WebSite* and *WebSite Specialization* (Figure 2).

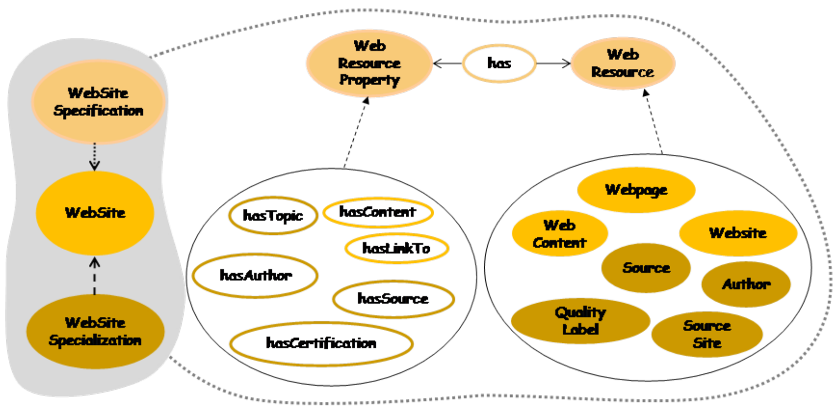

Fig. 2. WebSite Ontology described by the WebSite Specification Ontology

The main concepts of the *WebSite Specification* ontology are *WebResource* and *WebResourceProperty*. A web resource is any resource which is identified by a URL; for instance a webpage. Web resource properties models the properties that can be attached to a web resource, for instance, *hasContent*, *hasSource*, *hasAuthor*, etc. The *WebSite* ontology has as main concepts: *WebContent*, *WebPage* and *WebSite*, that are more specific. The *WebSite Specialization* ontology adds properties to these main concepts, such as *hasAuthor* and *hasSource* depending on the application environment.

In this ontology network, the most interesting feature is the use of the *isTheSchemaFor* relationship. The *WebSite Specification* ontology plays the role of metamodel for the *Website* and *WebSite Specialization* ontologies. Thus, the concepts and relations of these two ontologies are instances of the concepts *WebResource* and *WebResourceProperty* in the *WebSite Specification* ontology. This matchs the formal definition of the *isTheSchemaFor* relationship, where a mapping is defined between instances that asserts the concepts (ABox) in the metamodel (*WebSite Specification* ontology) and concepts and relations (TBox) in the model (*WebSite* and *WebSite Specialization* ontologies).

Quality Assurance ontology network is composed by three ontologies: *Metric Specification*, *Quality Specification* and *Quality Assessment*, as shown in Figure 3. These ontologies conceptualize metrics, quality assurance specifications and quality assessments, respectively, as is detailed in Section 4.

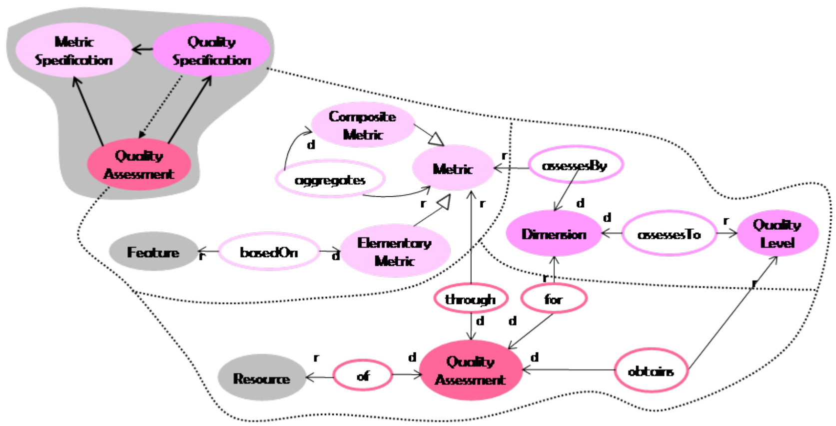

Fig. 3. Quality Assurance Ontology Network

As is showed in Figure 1, the *Quality Specification* ontology is related with the *Metric Specification* ontology through the *usesSymbolsOf* relationship; since a dimension of quality is always based on a metric. In this case, the occurrence of the *usesSymbolsOf* relationship is given by the *assessedBy* property that associates to each quality dimension the corresponding metric. It is the case where although two ontologies (*Quality Specification* y and *Metric Specification*) must be kept separate, there exists one ontology that needs to be linked to one or more concepts of another ontology, because some properties (in this case: *assessedBy* property) of it take values in individuals classified by classes in the used ontology (concept Metric of the *Metric Specification* ontology). If we review the given definition of the *usesSymbolsOf* relationship, the *Quality Specification* ontology "abstracts" from the particular ontology reused (*Metric Specification* ontology), focusing in the symbols to be reused (*Metric* concept), assuring the safety of the ontology reused.

Here it is important to clearly establish when to apply the *isAConservative-ExtensionOf* relationship and when to apply the *usesSymbolsOf* relationship. Reviewing their definitions, the former could be considered as a particular case of the latter, since in the *isAConservativeExtensionOf* relationship a ontology is enterely included in another one, while for the *usesSymbolsOf* relationship an ontology includes some elements of another ontology. But there exist a conceptual difference, which is important to consider when both relationships are used in a concrete case study. Below we explain the difference.

For the *usesSymbolsOf* relationship, although the domains of the involved ontologies are sematically related, the ontologies play different roles (for example a ontology models dimensions and another one models metrics). Thus, it can be inferred that for the *usesSymbolsOf* relationship the related ontologies are kept as separate ontologies, despite of one ontology is linked to the other by the need of reusing some concepts and individuals. However, for *isAConservativeExtensionOf*, the idea is that an ontology extends all the model of the other, specializing the represented knowledge.

In this work, the *Context* and *Recommendation* ontology networks are omitted, they are modeled through the *isTheSchemaFor* and *usesSymbolsOf* relationships.

5.2 The Health Ontology Network as a Network of Ontology Networks

The above presented ontology networks are also interrelated among each other. Mainly, they are related by the *usesSymbolsOf* and *mappingSimilarTo* relations (Figure 1).We have just illustrated the *usesSymbolsOf* relationship in the domain ontology networks (Section 5.1). The *usesSymbolsOf* relationship links a ontology to individuals of concepts of another ontology, in such a way that although they are separate ontologies, one ontology depends on the other, since it has properties that involves individuals of it. On the other hand, the *mappingSimilarTo* relationship, keeps the related ontologies even more independent. As was formalized in the definition, a mapping is defined between concepts of two ontologies, but none of them depends on the other, sharing a subset of instances that assert the mapped concepts. This is the reason why *mappingSimilarTo* is the relationship that fits in most of the links identified between ontologies from different domains, as Figure 1 shows.

For instance, the *mappingSimilarTo* relationship is used between *Quality Assessment* and *WebSite* ontologies of the *Quality Assurance* and *WebSite* domains respectively. It was defined an alignment between the *Resource* and *WebContent* concepts, in this particular case study of the health domain. But if our case study were about quality assessment of leaning objects, in the educational domain, we would define a alignment between the *Resource* and *LearningObject* concepts, and so on, depending on the nature of the individuals to be assessed.

The *mappingSimilarTo* relationship is also used between *Metric Specification* and *WebSite Specification* ontologies of the *Quality Assurance* and *WebSite* domains respectively. It was defined an alignment between the *Feature* and *WebResourceProperty* concepts. Thus, it is possible to specify that a metric is based on some property of a web resource. Here, it is possible to appreciate the convenience of having some ontologies that plays the role of metamodel for others, because the instances (ABox) of the *WebResourceProperty* concept of the *WebSite Specification* ontology are relations (TBox) of the *WebSite* ontology (properties of web contents).

The *usesSymbolsOf* relationship, can be identified (Figure 1) between *WebSite Specialization* and *Alzheimer* ontologies of the WebSite and Health domains respectively. For instance, the *hasTopic* property, from the *WebSite Specialization* ontology takes values in the *Alzheimer* ontology.

6 Conclusions and Future Research Directions

In this paper we have explicitly defined a set of ontology relationships which allow us to express different links among the ontologies of a ontology network. We give a formal definition of each relationship, based on the Description Logics formalism, which prevents from contradictory inferences tailored in an ontology network.

In addition, we have used the defined relationships to describe an ontology network that models the different domains related to a health recommender system. Thus, we have explicited the relationships among the ontologies that compose each domain ontology network as well as those which link the domain ontology networks to make up the *Health* ontology network.

The present work is a first theoretic approach which aims to keep the logical consistency of the ontology network model and its directions is towards the obtaining of a complete and minimal set of ontology relationships necessary and sufficient to build an ontology network.

Starting from the presented design, good practices on Ontology Engineering lead to evaluate the model in an interaction between ontology engineers and domain experts. From this evaluation, it is expected to reach a final refinement of the structures which compose the ontology network, capitalizing it in methodological results.

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