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Full Length Research Paper

Analysis of the OWL ontologies: A survey

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Web ontology language (OWL) is one of the last recommendations from the World Wide Web Consortium (W3C) to develop ontologies. The use of OWL ontologies must involve the possibility of the evaluation of quality and correctness. A wide diversity of tools and metrics has been proposed to reach this goal. ONTOMETRIC, OntoQA and Protégé represent the most important tools to evaluate ontologies that usually support metrics. This paper analyses all these tools and makes a proposal to normalize the ontology metrics as a pre-process to apply structural metrics. Also, an OWL-VisMod instrument is introduced as a visual modeling tool with capabilities of metric calculation, especially metrics related to semantics. Nevertheless, it also includes metrics for the schema such as diverse counters for subclasses, object and data type properties and individuals. Finally, diverse visualisations targeted to represent the proposed metrics are included.

Key words: Ontology metrics, ontology construction support tools, ontology visualization, web ontology language, web ontology language -VisMod.

INTRODUCTION

In general, an ontology formally describes a domain of discourse. Typically, an ontology consists of a finite list of terms and the relationships among these terms. Ontologies play an important role in providing shared knowledge models to semantic-driven applications targeted by Semantic Web. Ontologies have been widely used in the context of 'knowledge management systems' (Bera 2007), representing a crucial aspect of the semantic technologies even from the point of view of the industry. Currently, different semantic technologies have been proposed in diverse fields such as the 'information technology' platforms such as RDi-Advise (Colomo-Palacios et al., 2010), information retrieval systems based on semantics (Akcapinar-Sezer, 2010), visualisation on mobile devices (Akcay and Altan, 2011), the common semantic web services (Comert et al., 2010) or the analysis of social networks (García-Crespo et al., 2010). Ontology metrics represent an important approach because of the fact that they can help assess and qualify an ontology. From the viewpoint of ontology developers by assessing the quality of an ontology, they can automatically recognise areas that might need more work and specify some parts of the ontology that might cause problems. In addition to this, metrics are useful in the process of whether or not to reuse an ontology because before using a previously defined ontology it would be desirable to evaluate it in order to determine the value of using it again. Metrics should always be taken into account when evaluating ontologies both during the engineering and application processes. Most metrics are defined from empirical analysis and after being tested with real ontologies they are evaluated. Ontologies are basically hierarchical data, and the metrics should be more conceptual than for instance, software metrics that are more closely related to the source code. Nevertheless, some approaches taken from the 'software engineering field' have been adapted and used in the ontologies field.

There are two different approaches of metrics for ontologies (Tartir et al., 2005), those ones targeted to measure any aspect of the structure and those aimed at

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the semantics. Most of the metrics, especially those targeted to the structure are simple quantitative values that measure some aspect on the ontology. These measurements are used to analytically provide an evaluation. On the other hand, the metrics targeted to the semantics provide more than a simple measurement. They also require an interpretation to evaluate the ontology. In this paper some metrics targeted to the semantics are described in order to measure the coupling among classes. As well as this, some visualisation techniques are introduced just to help users to understand what semantic metrics really mean. Users can interact with the visualisations to analyse and interpret these metrics beyond a simple numerical value. The methodology followed in this paper to perform the survey has been based on the Kitchenham and Charters (2007) approach. This methodology has been adapted to the specific needs of this survey. In a general workflow, the phases described as follows have been performed for this survey, starting with a planning phase which includes the identification of the need for a review, in this case a metrics review; followed by a specification of the research question(s) and the development of certain criteria such as which metrics have been defined for assessing web ontology language (OWL) ontologies?, or what do these metrics measure?; to finally concluding with the development and evaluation of a review protocol. This is followed by the proper conduction of the review including the phases regarding the identification of the research, data extraction and the analysis of the quality assessment of the metrics, in this case some metric values from different tools. The third phase is associated with reporting the survey that includes the mechanisms of dissemination (publication), the format of the report and the evaluation. Both these activities are carried out in this paper and described as follows: this paper analyses the diverse metrics proposed for OWL ontologies. It starts with a brief introduction of ontologies and metrics, then, the second section summarises the diverse metrics proposals.

The third section discusses the results, which basically provides an overview of the current tools that implement some metrics, with special focus on OWL-VisMod. The fourth section discusses the different approaches as well as comparing and contrasting the different metrics. Finally, the fifth section draws the conclusions.

MATERIALS AND METHODS

As described earlier, the methodology used for this research is the approach for 'software engineering' described in Kitchenham and Charters (2007) and redefined in Kitchenham et al. (2009), with some modifications as some phases have been changed to be adequate to the task of this survey. Kitchenham et al. (2009) started their method specifying the research questions. In this paper, these specific questions are: which metrics have been defined for assessing OWL ontologies?, what do these metrics measure?, what are these metrics targeted to (schema or semantics)?. These questions are the main research questions addressed by this study. Because of this methodology, it targets the software engineering field; diverse phases belonging to this field have not been performed. Even though software engineering and ontological engineering have many activities in common, they do not have exactly the same. The second developed phase was a search process in order to get the proposals about metrics from the literature. This phase included an inclusion and exclusion decision making process. The exclusion of proposals was related to the filtering of those based on OWL, without taking into account other languages such as DAML, RDF, RDF-SCHEMA, etc., even though some of them are mentioned as follows: once the search process was done, the study follows with the collection and analysis of the information including a quality assessment of the proposals. Once the analysis was performed, the final phase included the definition of the mechanisms to report the results as well as contrasting the diverse results.

The material included in this survey, covers the diverse papers describing metrics for ontologies. These metrics are mainly based on two approaches: the first one is focused on the schema/structure of the ontology and the second one focused on the semantics of the ontology. The diverse ontological metric proposals are described as follows: Vrandečić and Sure (2007) describe some metrics to normalise ontologies; they reviewed the current state-of-the-art process and proposed normalisation as a pre-process to apply structural metrics. This normalisation process consists of five steps: to name anonymous classes, name anonymous individuals, classify hierarchically, unify names, propagate individuals to the deepest possible classes and finally, normalize object properties. This proposal is focused on content metrics based on OntoMetric framework and fundamentally have been proposed to improve ontology behaviour or to fix some mistakes. Alani and Brewster (2006) and Alani et al. (2006) propose some metrics to rank ontologies. Essentially, this proposal consists of a Java Servlet processing some keyword inputs entered by the user. Then the framework searches using the Swoogle (http://swoogle.umbc.edu) engine and retrieves all the URIs representing the ontologies related to these keywords. Then the framework searches its internal database to see if these ontologies have been previously analysed and retrieves this information. Finally the framework ranks the retrieved ontologies. AKTiveRank relies on Jena (http://jena.sourceforge.net) that is the background management of ontologies. It uses a Jena MySQL database back-end to store the ontologies. Jena API is also used to perform some of the analysis of the ontology structures. AKTiveRank applies four types of measures to rank ontologies. One of the first reported measures was the centrality measure (CEM). This measure aims to assess how representative a class is of an ontology based on the observation of the location of a class in the hierarchy. Another proposed metric is density measure (DEM) that calculates the information content of a class. These two metrics have shown that classes at mid-hierarchical levels tend to be more detailed than others. The class match measure (CMM) is meant to evaluate the coverage of an ontology for the given search terms. AKTiveRank looks for classes (within an ontology) that have labels matching a search term either exactly or partially. The semantic similarity measure (SSM) calculates how close the classes that match the search terms are. SSM is measured from the minimum number of links that connects a pair of concepts and these links can be "is-a" relationships or object properties. Finally, the authors propose the betweenness measure (BEM), which calculates the shortest paths that pass through each node in the graph of each queried concept in the given ontologies.

The authors also describe an experiment using their metrics and analyse the results. Orme et al. (2006) proposed a set of coupling metrics for ontology-based systems represented in OWL. These metrics are the number of external classes (NEC), references to external classes (REC) and included reference (RI). This proposal defines a new type of coupling measurement for system development that defines coupling metrics based on ontology data and its structure. The first proposed metric is NEC which represents the number of distinct external classes defined outside the ontology but used to define new classes and properties in the ontology. The external classes can include standard classes defined as ontology language primitives and user-defined classes from other ontologies. The second metric REC is the number of references to external classes in the ontology. As we earlier described, NEC is a direct measure of the number of classes in the ontology. REC is a direct measure of the number of fanouts (in this case, fanouts are different class hierarchies with external roots) within the ontology resulting from external classes. RI is a direct measure of the number of references included in the ontology. Yao et al. (2005) proposed some cohesion metrics for ontologies. These metrics represent a set of ontology cohesion metrics to measure the modular relatedness of OWL ontologies. These metrics are a number of root classes (NoR), a number of leaf classes (NoL) and an average depth of inheritance tree of all leaf nodes (ADIT-LN). The authors define NoR metric as the total number of root classes explicitly defined in the ontology. A root class in an ontology which means that the class has no semantic super class explicitly defined in the ontology. NoL metric is defined as the number of leaf classes explicitly defined in the ontology. A leaf class in an ontology means the class has no semantic subclass explicitly defined in the ontology. Finally ADIT-LN is defined as the sum of depths of all paths divided by the total number of paths. A depth is the total number of nodes starting from the root node to the leaf node in a path. The total number of paths in an ontology is all distinct paths from each root node to each leaf node if there exists an inheritance path from the root node to the leaf node.

The root node is the first level in each path. These metrics are defined to be used when diverse ontologies are combined and the primary goal is to reduce coupling that can cause failures in the runtime use of these ontologies. The authors have documented a case study in the field of bioinformatics and genomics, where the ontologies are generally related to characterising the molecular structure of living things. Yinglong et al. (2010) propose another set of ontology cohesion metrics to measure the modular relatedness of ontologies in dynamic contexts and changing the Web. These metrics have been defined taking into account the principle cohesion from the ‘object oriented approach’ adapted for ontologies. The authors concentrate on measuring inconsistencies in ontologies and fully consider the ontological semantics rather than the structure. The metrics they propose are the number of ontology partitions (NOP), the number of minimally inconsistent subsets (NMIS) and the average value of axiom inconsistencies (AVAI). This work also describes the algorithms to compute these metrics and validate the metrics by using validation frameworks. These metrics are focused on assessing the quality of ontologies. The authors define the NOP metric as the number of semantic partitions of a knowledge base. NMIS is defined as the number of all minimally inconsistent subsets in a knowledge base. This metric is useful to measure the scope of inconsistency and the impacts of a knowledge base. The third metric AVAI, which is defined as the ratio of the sum of inconsistency impact values of all axioms and assertions to the cardinality of the knowledge base. Moreover, the article analyses and validates the proposed metrics. Generally speaking, the advantages of these metrics include the possibility of assessing the quality of a consistent ontology. OntoClean methodology proposed by Guarino and Welty (2002), and later redefined by Guarino and Welty (2004) was first introduced in 2000 and modified in the subsequent years. It proposes the use of some defined metaproperties. These metaproperties are essence, rigidity, unity, identity and dependency. The authors have borrowed these concepts from their ancient philosophical counterparts.

A characteristic of an entity is essential if it is true in every possible world. A special form of essentiality is rigidity; a property is rigid if it is necessary in all possible instances. An instance of a rigid property cannot stop being an instance of that property in a different world. On the other hand, the identity refers to the problem of being able to recognise individual entities in the world as being the same (or different) and unity refers to being able to recognise all the parts that form an individual entry. The methodology consists of assigning these metaproperties to the entities in order to provide a logical and semantic meaning. The application of these metaproperties results on imposing several constraints on the taxonomic structure of an ontology and allows the development of a conceptual analysis of the concepts and their validity. Moreover this methodology allows us to analyse and detect not logically consistent relationships. Yang et al. (2006) proposed metrics from a different point of view, taking into account the evolution of the ontologies. The authors suggest a metrics suite of complexity, which mainly examines the quantity, ratio and correlativity of concepts and relationships in order to evaluate ontologies from the viewpoint of their complexity and evolution. These metrics are divided into two groups: primitive metrics and complexity metrics. The primitive metrics include TNOC (total numbers of concepts or classes), TNOR (total number of relations), TNOP (total number of paths), where a path is defined as a trace that can be taken from a specific concept to the most general concept in the ontology. The first ‘complexity metric’ defined is the average relations per concept that is calculated by dividing TNOR by TNOC. The second metric is the average paths per concept that is calculated by dividing TNOP by TNOC. Lida et al. (2009) described an experiment that analyses the contents of retrieved blog entries using an ontology. It refers to evaluation expression ontology that performs a morphologic analysis and the syntactic analysis of blog contents retrieved from the internet and then evaluates a positive or negative rating of the blog contents. They developed an ontology to evaluate the expression, as well as a maintenance tool to measure the quality of ontology and the maintenance costs.

The paper proposes and describes diverse naive metrics applied to a maintenance experiment: the number of increased instances, the entry error rate of instance, precision, recall, slope of precision/recall and variance of precision/recall. The number of increased instances is a measure of the relation between ontology size and accuracy. It involves measuring the number of instances before and after maintenance and the number of instances added per maintenance time. The entry error rate of instance is the ratio of inappropriate instances judged by an engineer with seasoned knowledge of an ontology in all the instances added by maintenance. It evaluates the instance that cannot be used in the system because the system does not use all instances. The precision shows the ratio of sentences that actually include positive/negative expression to sentences that include positive/negative expression judged by system analysis. The recall shows the ratio of sentences that include positive/negative expression judged by system analysis to sentences that include positive/negative expressions judged manually. Finally, slope of precision/recall measures a percentage of increase and variance of precision/recall measures variability of index values of multiple products. Brank et al. (2005) provide a survey of diverse ontology evaluation techniques and classify them in diverse categories. These categories are lexical, vocabulary or data layer, hierarchy or taxonomy, other semantic relations and context or application level. The first level is identified as lexical, vocabulary or data layer, where the focus is on which concepts, instances, facts, etc., included in the ontology, as well as the vocabulary used to represent or identify these concepts. The evaluation of this level tends to involve comparisons with various sources of data concerning the domain problem.

The second is identified as hierarchy or taxonomy. This level takes into account the “is-a” relationships defined in the ontology. The third level involves the other semantic relations which are evaluated separately. The next is the context or application level. It refers to all the references to this ontology made from diverse external ontologies. The syntactic level refers to the evaluation of the matching of the syntactic requirements of the language in which the ontology has been described. The last level is related to the structure, architecture and design. This level is primarily of interest in manually constructed ontologies. It allows on ontology to meet certain pre-defined design principles or criteria. An interesting metrics suite has been proposed by Burton-Jones et al. (2005) which is targeted to DAML language. The contribution of this research is to provide a theory-based framework that developers can use to develop high quality ontologies and that applications can be used to choose appropriate ontologies for a given task. The proposed metrics are focused on assessing the syntactic, semantic, pragmatic and social quality of ontologies. These metrics were implemented in an automated ontology auditor. This is an agent that operates autonomously to assess the value of an ontology before an ontology is used by an application. Even though these metrics are focused on DAML, these concepts can also be used with OWL ontologies. Maynard et al. (2006) discuss existing evaluation metrics and propose a new method for evaluating the ontology population task. This paper examines OBIE (ontology based information extraction) which is used as the basis for automatic semantic annotation/metadata extraction. Then, the authors describe some existing metrics for the evaluation of information extraction such as to calculate the precision and recall, the cost-base evaluation metric and the learning accuracy.

Precision measures the number of correctly identified items as a percentage of the total number of identified items. In other words, it measures how many items which the system identified were actually correct, regardless of whether it also failed to retrieve correct items. Recall measures the number of correctly identified items as a percentage of the total number of correct items. In other words, it measures how many of the items that should have been identified actually were identified, regardless of how much spurious identification was made. The ‘cost-based evaluation metric’ commonly known as CBE, characterises the performance in terms of the cost of the errors. The authors propose a new distance metric that they call BDM; this provides a formula to calculate this metric based on some measurements previously defined such as MSCA, CP, DPR and DPK. The authors of this paper evaluate their metrics and the conceptual matching with respect to an ontology by developing different experiments. MSCA is the most specific concept common to the key and response paths. CP is the shortest path from root concept to MSCA. DPR is the shortest path from MSCA to response concept. DPK is the shortest path from MSCA to the key concept. On the other hand, García et al. (2010a) proposed diverse coupling metrics focused on the well-known CBO (coupling between objects) metric for the object-oriented software engineering field. As a metric for coupling, CBO value has been defined as proportional to the number of non-inheritance related couples with other classes; it means the total number of couples that one class has with other classes. This metric was proposed by Chidamber and Kemerer (1991). Based on CBO, counterpart focused OWL ontologies are defined as: CBE metric (coupling between entities) to measure the number of properties (relationships) among classes in an OWL ontology. It is important to distinguish between the proposed metric in this work and the CBE concept previously discussed which refers to ‘cost-based evaluation’, thus, there are two different concepts.

The coupling among classes in an OWL ontology is based on the object properties that relate classes in the domain with classes in the range, creating a coupling relationship among them. Diverse variations from CBE metric have also been proposed such as CBE-out, CBE-in, CBE-io and SC. Differences among them are when classes are defined in the domain or the range of the property. The CBE-out metric of the class C is defined as the total number of properties of the ontology, where the proper class C is located in the domain of the property. In contrast, the CBE-in metric for a class C is defined as the total number of properties of the ontology where the class C belongs to the range of the property. The metric CBE-io is defined as the half value of the total number of inverse properties where the class C belongs to the domain for a property and the range of their inverse properties. Finally, self coupling (SC) metric value is defined as the total number of properties where the class C belongs to the domain and the range of them. CBE final value, representing the total coupling of a certain class is calculated by adding the values of metrics CBE-in, CBE-out, CBE-io and SC. These metrics are useful to analyse the grade of coupling which means the related connections among diverse concepts. It is important to clearly distinguish between these metrics and coupling metrics proposed by Orme et al. (2006). Metrics NEC, REC and RI previously discussed refer to a certain type of coupling among classes in different ontologies; in contrast, the metrics proposed by García et al. (2010a) measure the internal coupling of classes in the same ontology. The metrics proposed by García et al. (2010a) have been tested through diverse publicly available ontologies such as SWETO, C2IEDM, JC3IEDM3, portal or terrorism.

The results of these tests are available in García et al. (2010b) as well as the implementation of a visualisation framework focused on our coupling metrics.

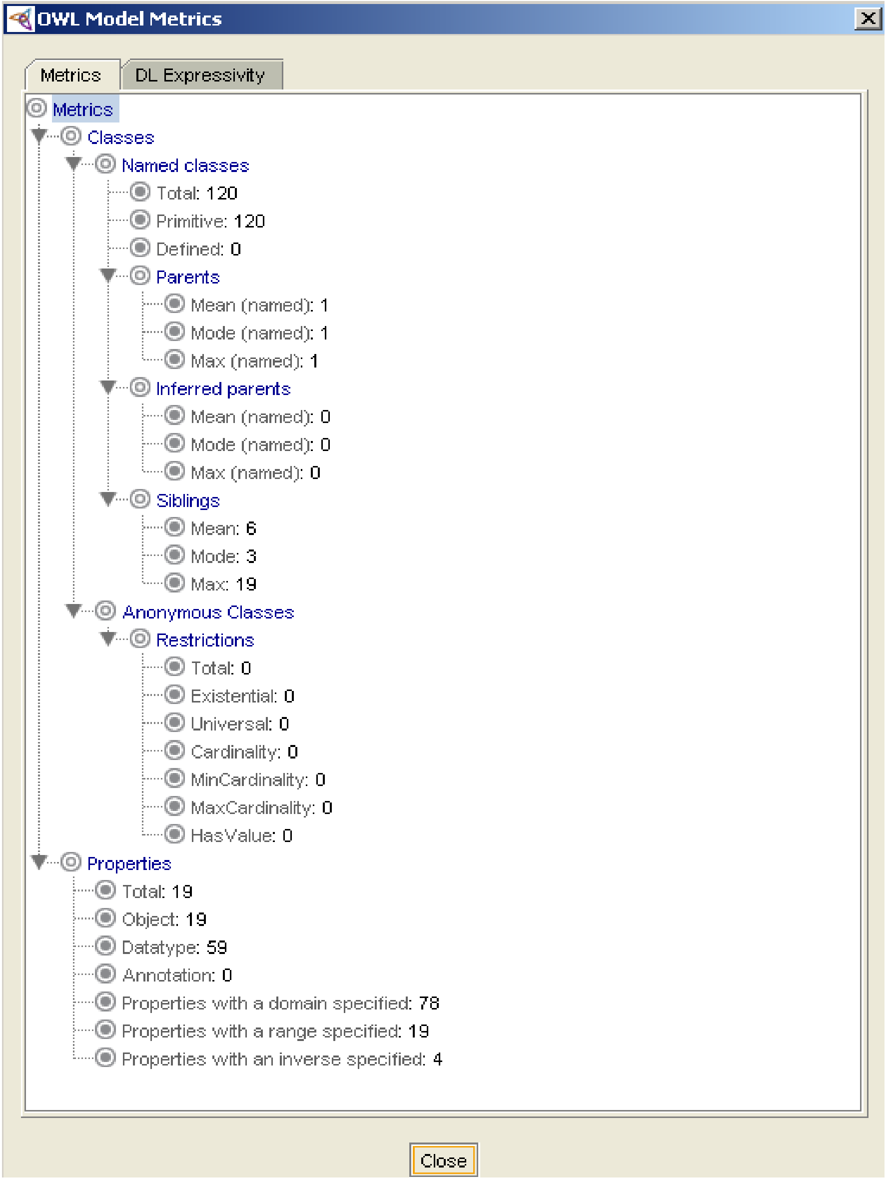
RESULTS

The result of these proposals is the proper implementation of them in a set of tools that lets the user measure an ontology through these metrics. Below, the most important tools for implementing metrics for OWL ontologies are summarised. ONTOMETRIC, OntoQA and Protégé represent the main available proposals. OntoQA (Tartir et al., 2005; Tartir and Arpinar, 2007) represents the main proposal about metrics on ontologies. It proposes some ‘schema metrics’ to measure the richness of schema relationships, attributes and schema inheritance. These metrics are focused on evaluating the ontology in general. The proposed metrics are class richness, average population, cohesion, importance of a class, fullness of a class, class inheritance and class relationship richness, connectivity and readability. Class relationship richness is defined as the number of relationships that are being used by instances that belong to the class. On the other hand, the connectivity of a class is defined as the number of instances of other classes that are connected to instances of the selected class. According to Tartir et al. (2005), OntoQA divides the metrics into two related categories: the schema metrics (mentioned earlier) and instance metrics. The first category evaluates the ontology design and its potential for rich knowledge representation. The second category evaluates the placement of instance data within the ontology and the effective usage of the ontology to represent the knowledge modelled in the ontology. Schema metrics include relationship richness, attribute richness and inheritance richness. On the other hand, instance metrics include class richness, average population, cohesion, importance, fullness, inheritance richness, relationship richness, connectivity and readability. Attribute richness (AR) is formally defined as the average number of attributes per class. Inheritance richness (IR) describes the distribution of information across different levels of the ontology's inheritance tree. Class richness (CR) measures the distribution of instances across classes. The number of classes that have instances is compared with the total number of classes, giving a general idea of how many instances are related to classes defined in the schema. The average population (P) is an indication of the number of instances compared to the number of classes.

Cohesion (Coh) is formally defined as the number of separate connected components of the graph representing the knowledge base (KB). Importance of a class (Imp) measures the percentage of instances that belong to classes at the subtree rooted at the current class with respect to the total number of instances. Fullness (F) of a class C is the actual number of instances compared to the expected number of instances. Relationships richness (RR) is a metric that reflects how much of the properties in each class in the schema are actually being used at the instances level. RR is formally defined as the number of relationships that are being used by instances 'I' that belong to the class C, compared to the number of relationships that are defined for C at the schema level. Finally, readability metric indicates the existence of human readable descriptions in the ontology such as comments, labels or captions. It is formally defined as the sum of the number of attributes that are comments and the number of attributes that are labels the class has. Currently protégé (http://protege.stanford.edu/) (Gennari et al., 2003) is the most widely used tool to create or modify an ontology. Metrics are classified into six categories. The first one is related to general metrics such as counters for classes, object properties, datatype properties and individuals. The second category is related to class axioms and includes counters for subclass axioms, equivalent class axioms, disjoint class axioms, GCI and hidden GCI. The third category includes counters for object property axioms. These counters are a total of sub object properties; equivalent, inverse, disjoint, functional, inverse functional, transitive, symmetric, antisymmetric, reflexive and irreflexive object properties. As well as this, the object property domain and range counters are also included. The fourth category is dedicated to datatype property counters. This category includes total values for sub datatype properties, equivalent, disjoint and functional datatype properties as well as counters for the data properties domain and range. The fifth category is focused on individuals; it defines counters for class assertions, object and datatype property assertions, negative object and negative datatype assertions and same or different individual axioms. Finally, the last category involves annotation axioms and defines just two metrics, entity annotation axioms count and axiom annotation axioms count. All these metrics represent simple counters for the items in the ontology and do not provide any kind of semantic metric.

Figure 1 depicts a snapshot of 'protégé metrics screen' and it shows all the calculated values for an OWL ontology. ONTOMETRIC (Lozano-Tello and Gómez-Pérez, 2004) is a framework to measure the suitability of existing ontologies. This tool was defined to quantify the suitability of ontologies. The authors propose a taxonomy of 160 characteristics also called a multilevel framework of characteristics that provides the outline in order to choose and compare existing ontologies. This framework is used as a representation template of the information and starts by defining an analytic hierarchy process. This process involves building a hierarchy tree with the root node being the objective of the problem. The intermediate are the criteria and finally the lowest levels contain the alternatives. Then as the second step, the methodology applies the analytic hierarchy process to decide whether or not to reuse the ontologies. Framework possesses, in the superior level of the taxonomy have five basic aspects on the ontologies that are denominated dimensions. These dimensions are the main aspects that a user should take into account to examine an ontology to see if they can use it for their project. These dimensions are: content of the ontology and organization of their contents, language in which it is implemented, methodology that has been followed in the development, software tools used to build and edit the ontology and costs of the ontology that will be necessary in a certain project. This framework is the base on which to build an ontology in the ontology domain called 'reference ontology'. This ontology is built following the development methodology of ontologies METHONTOLOGY (Fernández-López et al., 1997).

In conclusion, the ONTOMETRIC is intended to decide on the reuse of ontologies in a new software project, more specifically to select the most appropriate ontology among various alternatives and to decide on the suitability of a particular ontology for the project. Ontology metrics (http://owl.cs.manchester.ac.uk/metrics) is a web-based tool that validates and displays statistics about an OWL ontology including the expressivity of the language it is written in. This tool calculates the same metrics than 'protégé'. These metrics include counters for classes, properties, individuals, logical axioms as well as specific counters described earlier in the 'protégé section'. This tool uses the OWL API (http://owlapi.sourceforge.net), a Java API and reference implementation for creating, manipulating and serialising OWL ontologies. Figure 2 shows a snapshot of the tool. The tool is accessed via a web browser where the XML code of the ontology is pasted on a text field and a Java servlet processes the code. The tool supports diverse ontology formats such as: RDF/XML, OWL/XML, OWL functional syntax, Manchester OWL syntax, OBO syntax or KRSS syntax. OWL-VisMod is a visual modelling tool provided with capabilities to calculate diverse metrics. Some of the most common metrics have been included especially those related with the schema, such as diverse counters

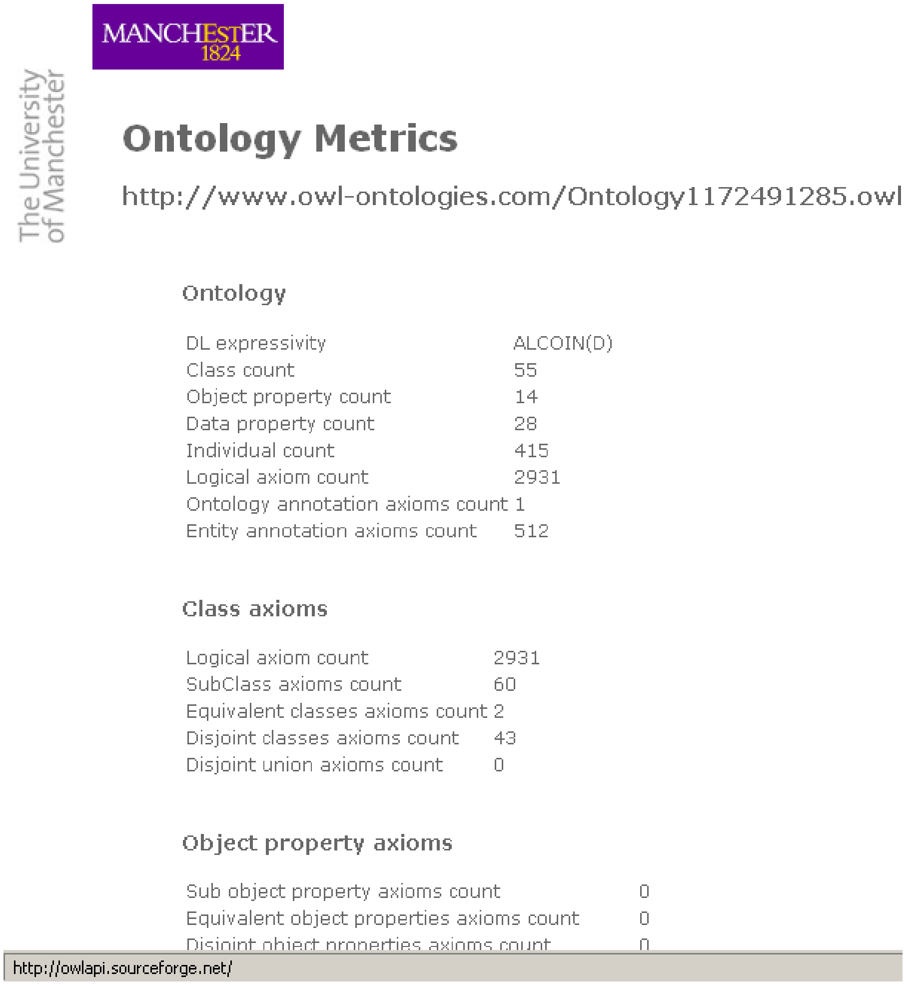


Metrics
- Classes
  - Named classes
    - Total: 120
    - Primitive: 120
    - Defined: 0
    - Parents
      - Mean (named): 1
      - Mode (named): 1
      - Max (named): 1
    - Inferred parents
      - Mean (named): 0
      - Mode (named): 0
      - Max (named): 0
    - Siblings
      - Mean: 6
      - Mode: 3
      - Max: 19
  - Anonymous Classes
    - Restrictions
      - Total: 0
      - Existential: 0
      - Universal: 0
      - Cardinality: 0
      - MinCardinality: 0
      - MaxCardinality: 0
      - HasValue: 0
- Properties
  - Total: 19
  - Object: 19
  - Datatype: 59
  - Annotation: 0
  - Properties with a domain specified: 78
  - Properties with a range specified: 19
  - Properties with an inverse specified: 4

Figure 1. Protégé metrics screen snapshot that shows all the metric values calculated by protégé for OWL ontologies.

for subclasses, object, datatype properties and individuals. In addition to this, the main proposal related to metrics is the analysis of the coupling of the classes in ontologies. As has been previously described, CBE (coupling between entities) metrics are proposed and intend to analyse the coupling among the classes in an ontology. Also diverse visualisations have been defined to support the analysis of the metrics.

The first supported visualisation by OWL-VisMod is called table lens (Rao and Card, 1994). It is based on the use of the 'focus + context technique', which supports visualising an entire information structure at once as well as zooming-in and zooming-out on specific items. The table lens is used for visualising large tables and it offers a better performance than that of the normal tables. It includes the definition of a distortion function to develop the focus + context technique. The OWL-VisMod proposal defines one distortion to provide the focus to the highlighted element (row and column) as shown in Figure 3. The metrics are displayed in the last columns in the table lens in the following order: CBE-out, CBE-in, CBE-io, SC and CBE. Figure 3 also depicts the interaction within it. A distortion is performed over the highlighted row and column, and the internal values are shown. Each column can be ordered in an ascending or descending pattern or even hidden. In contrast to 'protégé and ontology metrics' that just show the metric values using a static table, this proposal lets the user interact with the



Ontology Metrics

http://www.owl-ontologies.com/Ontology1172491285.owl

Ontology

DL expressivity	ALCOIN(D)
Class count	55
Object property count	14
Data property count	28
Individual count	415
Logical axiom count	2931
Ontology annotation axioms count	1
Entity annotation axioms count	512

Class axioms

Logical axiom count	2931
SubClass axioms count	60
Equivalent classes axioms count	2
Disjoint classes axioms count	43
Disjoint union axioms count	0

Object property axioms

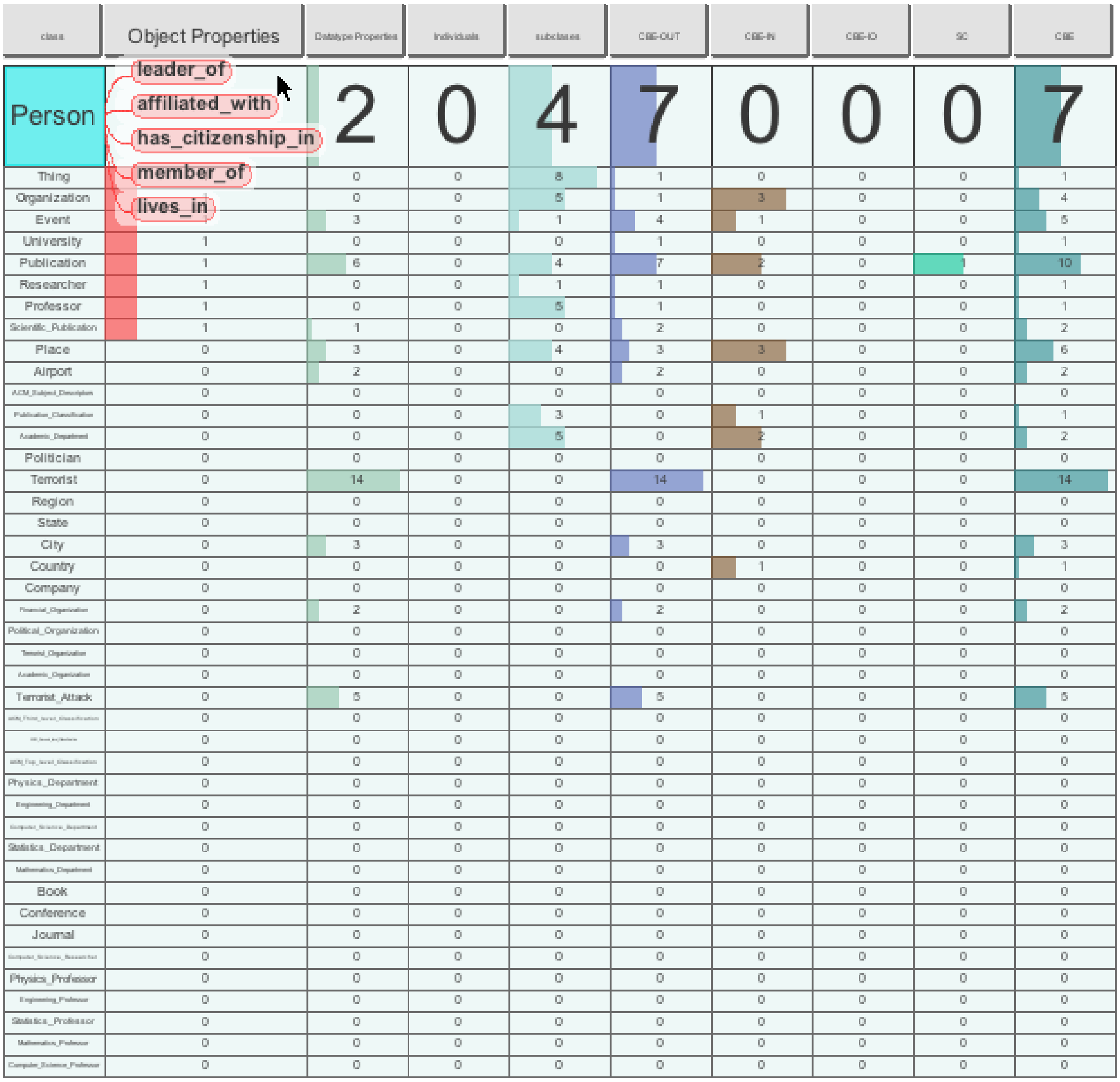
Sub object property axioms count	0
Equivalent object properties axioms count	0
Disjoint object properties axioms count	0

http://owlapi.sourceforge.net/

Figure 2. Depicts a snapshot of the tool OWL-API developed by the University of Manchester. It shows the metrics of an OWL ontology in a web-based interface. The XML code is pasted in an editable text field and then the metrics are processed and displayed.

visualisation to arrange or display the internal values. The table lens also displays the internal values, not just the numerical quantity but the concrete values as shown in Figure 3. This is a useful functionality because the user can get an overview of the numerical and analytical value by just pointing out the row and column and the concrete value is also shown which in contrast to the rest of the tools that just display a static table without any kind of interaction. Figures 4a and 4b illustrate a visualisation used to represent the coupling of a class which is completely described by García et al. (2010b). All the properties are organised in a radial layout surrounding the selected class which are located at the centre. Object properties are filled in a soft red tone while the datatype properties are in a soft green tone. The properties located right of the class correspond to those ones with the CBE-out metric value and while the properties located to the left correspond to those with the CBE-in metric value. Figure 4a depicts the semantic zoom over a class called ‘organization’, it shows that its CBE-out metric value is 2 because there are two object properties right to the class (responsible_for, located_in).

The logic interpretation of these properties would be: “an organization is responsible for an event”, and “an organization is located in a place”, where clearly the class organization belongs to the domain of both properties, whereas the classes: event and place belong to the range of both properties. On the other hand, the CBE-in metric value is 3 because three properties have the class organization in their range being these ones member_of, affiliated_with and leader_of. The logically interpretation of these properties would be: “a person is member of an organization”, “a person is affiliated with an organization”, and “a person is a leader of an organization”. These properties are also shown in Figure 3, where the class person is highlighted, showing its object properties.



class	Object Properties	Datatype Properties	Individuals	subclasses	CBE-OUT	CBE-IN	CBE-IO	SC	CBE
Person	leader_of affiliated_with has_citizenship_in member_of lives_in	2	0	4	7	0	0	0	7
Thing	[illegible]	0	0	8	1	0	0	0	1
Organization	1	0	0	5	1	3	0	0	4
Event	1	3	0	1	4	1	0	0	5
University	1	0	0	0	1	0	0	0	1
Publication	1	6	0	4	7	2	0	1	10
Researcher	1	0	0	1	1	0	0	0	1
Professor	1	0	0	5	1	0	0	0	1
Scientific_Publication	1	1	0	0	2	0	0	0	2
Place	0	3	0	4	3	3	0	0	6
Airport	0	2	0	0	2	0	0	0	2
ACM_Subject_Descriptors	0	0	0	0	0	0	0	0	0
Publication_Classification	0	0	0	3	0	1	0	0	1
Academic_Department	0	0	0	5	0	2	0	0	2
Politician	0	0	0	0	0	0	0	0	0
Terrorist	0	14	0	0	14	0	0	0	14
Region	0	0	0	0	0	0	0	0	0
State	0	0	0	0	0	0	0	0	0
City	0	3	0	0	3	0	0	0	3
Country	0	0	0	0	0	1	0	0	1
Company	0	0	0	0	0	0	0	0	0
Financial_Organization	0	2	0	0	2	0	0	0	2
Political_Organization	0	0	0	0	0	0	0	0	0
Terrorist_Organization	0	0	0	0	0	0	0	0	0
Academic_Organization	0	0	0	0	0	0	0	0	0
Terrorist_Attack	0	5	0	0	5	0	0	0	5
ACM_Third_Level_Classification	0	0	0	0	0	0	0	0	0
[illegible]	0	0	0	0	0	0	0	0	0
ACM_Top_Level_Classification	0	0	0	0	0	0	0	0	0
Physics_Department	0	0	0	0	0	0	0	0	0
Engineering_Department	0	0	0	0	0	0	0	0	0
Computer_Science_Department	0	0	0	0	0	0	0	0	0
Statistics_Department	0	0	0	0	0	0	0	0	0
Mathematics_Department	0	0	0	0	0	0	0	0	0
Book	0	0	0	0	0	0	0	0	0
Conference	0	0	0	0	0	0	0	0	0
Journal	0	0	0	0	0	0	0	0	0
Computer_Science_Researcher	0	0	0	0	0	0	0	0	0
Physics_Professor	0	0	0	0	0	0	0	0	0
Engineering_Professor	0	0	0	0	0	0	0	0	0
Statistics_Professor	0	0	0	0	0	0	0	0	0
Mathematics_Professor	0	0	0	0	0	0	0	0	0
Computer_Science_Professor	0	0	0	0	0	0	0	0	0

Fgure 3. The table lens visualisation technique showing the diverse metrics calculated in OWL-VisMod. All the values in the highlighted row are displayed using a focus + context technique.

Another interesting aspect is that the datatype properties have no values defined in their range, this aspect is represented with a question mark in Figure 4a. On the other hand, Figure 4b illustrates other coupled class, where for the property 'sao152994059', the domain is formed by four classes, represented as a cluster. The highlighted property 'sao1434436507' is defined with a dashed outline indicating that this property has been inherited from a superclass; it has not been defined in the selected class. All the properties defined in the selected class have a continuous outline to demonstrate this. Two ontologies have been used to describe these proposed visualisations. The first ontology is semantic web technology evaluation ontology (SWETO) version 1.4 (http://knoesis.wright.edu/library/ontologies/sweto/), a general-purpose ontology developed in 2004 and described by Aleman-meza et al. (2004), (Figures 3 and 4a describe elements from this ontology). The second ontology used to illustrate the diverse visualisations is SAO (sub-cellular anatomy ontology) version 1.2 (http://ccdb.ucsd.edu/SAO/1.2/SAO.owl) freely available and described by Fong et al. (2007). This ontology describes the subcellular anatomy of the nervous system, covering nerve cells, their parts and interaction among these parts. It was built in protégé 3.2.x in OWL 1.0, conforms to OWL-DL rules, it has almost 800 classes. Figures 4b and 5 represent two views of this ontology. Figure 5 shows a general view of the global coupling of the ontology SAO

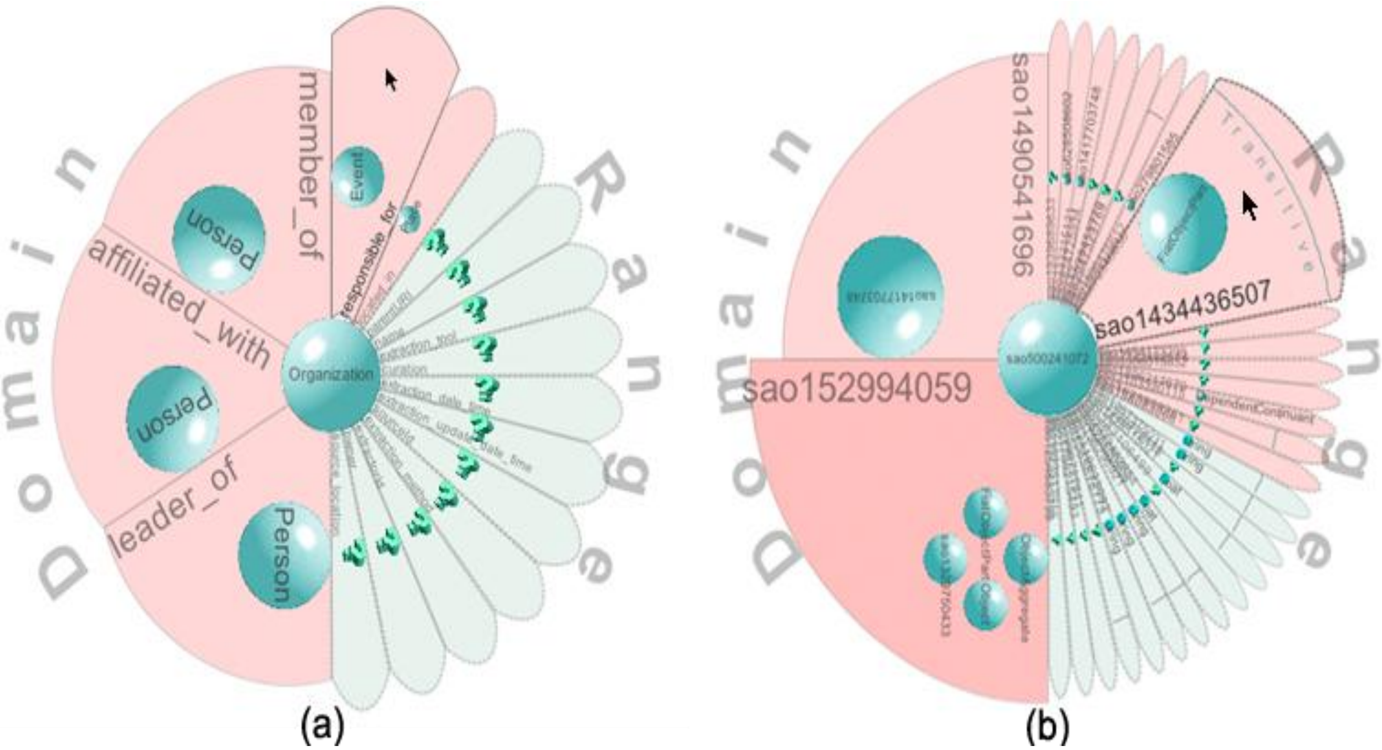


Figure 4. Two views of the coupling of different classes. The properties are located in a radial layout surrounding the selected class. Object properties are filled in a soft red tone while the datatype properties are filled in a soft green tone.

highlighting the property 'sao152994059' in order to display a representation of its domain and range.

The domain of the property is represented by a cluster of classes and the range is illustrated with just one class. This visualisation clearly represents the logical model of a property with its domain and range and all the characteristics (functional, symmetric, inverse) of the property are also displayed in the visualisation.

DISCUSSION AND CONTRASTING TOOLS

Analysing the diverse metrics that have been discussed earlier, it is possible to contrast them by putting a special focus on aspects, based upon the fact that metrics are centred on semantics or the structure. Table 1 summarises the metrics previously analysed according to the parameters: semantic or structure focused, ranking, cohesion and coupling. Comparing diverse metrics analysed, it may be interesting to express that OntoQA offers the best set of metrics for analysing the structure of the ontologies; AKTiveRank is an interesting proposal to rank ontologies according to certain search criteria. It defines 4 metrics to rank the ontologies: centrality measure (CEM), density measure (DEM), class match measure (CMM) and semantic similarity measure (SSM). The AKTiveRank approach is quite different from the others. Most of the metrics are calculated over an ontology, but AKTiveRank searches for diverse ontologies according to a certain keyword, then it ranks all the results in order to relate the ontologies with the keyword. Just Yinglong et al. (2010) proposal and OntoClean are focused on the semantics. On the other hand, Orme et al. (2006) and Yinglong et al. (2010) and OntoQA have proposed different metrics to calculate the cohesion. It is important to highlight that they represent three completely different ways to define cohesion. OntoQa defines cohesion as the number of separate and connected components of the graph representing the 'knowledge base'. In contrast, Orme et al. (2006) proposes that metrics are completely related to the structure and the hierarchy of the ontology and measure the modular relatedness of OWL ontologies while Yinglong et al. (2010) focuses on measuring inconsistencies in ontologies in the context of dynamics and changing web.

Seven cohesion metrics have been analysed, which are: number of root classes (NoR), number of leaf classes (NoL), average depth of inheritance tree of all leaf nodes (ADIT-LN), number of ontology partitions (NOP), number of minimally inconsistent subsets (NMIS) and the average value of axiom inconsistencies (AVAI) and the cohesion metric from OntoQA (Coh). The Orme et al. (2006) metrics proposal represents the coupling among entities from diverse ontologies. The García et al. (2010a) metrics proposal is focused on coupling from a

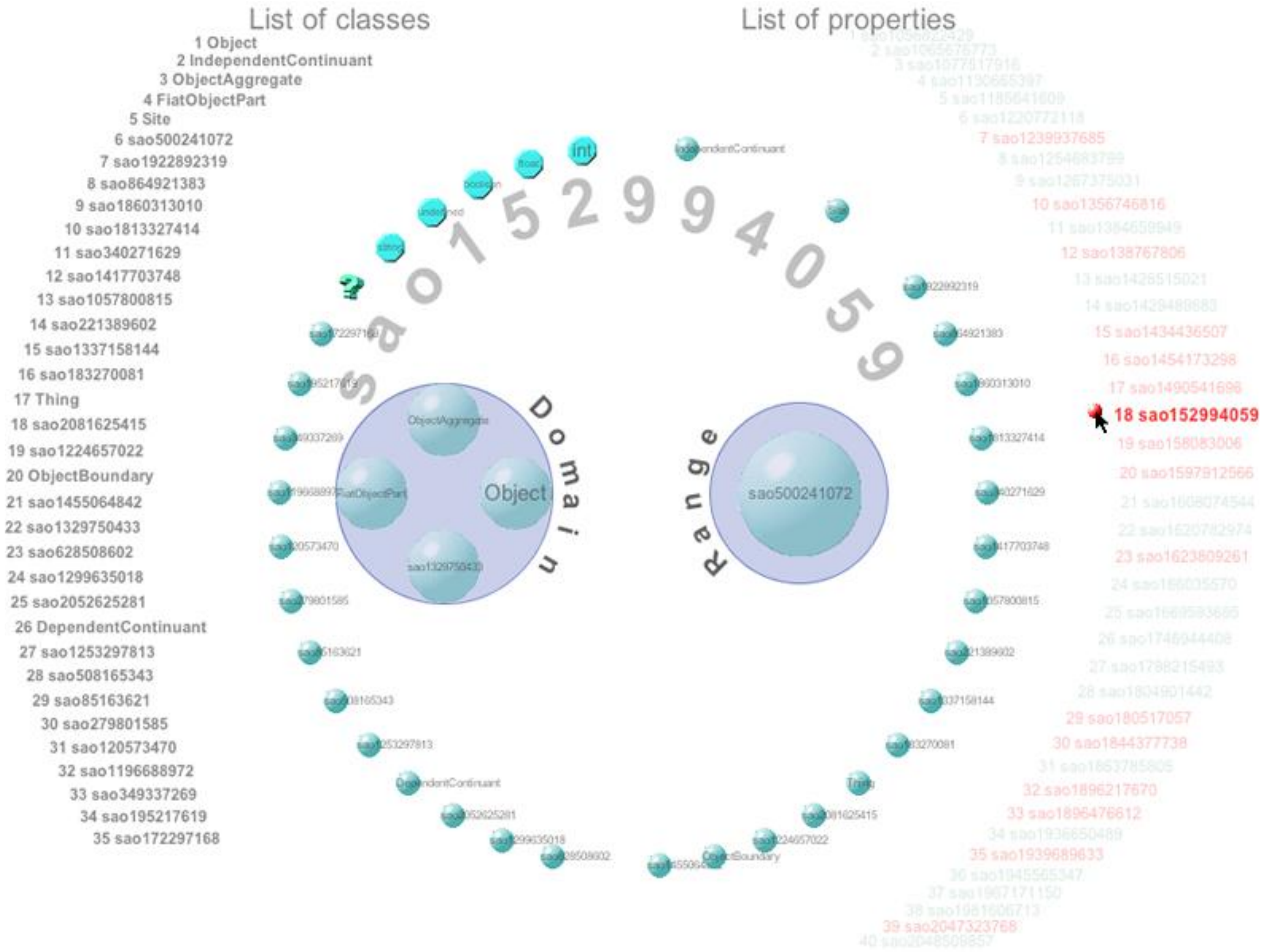


Figure 5. A global view of the representation of the domain and range of the property sao152994059. The domain is represented as a cluster of classes with 4 elements, while the range is shown with just one class.

different point of view. While Orme et al. (2006) propose coupling metrics from classes defined out of the current ontology, it means coupling this ontology with other ontologies. This type of coupling refers to importing classes defined outside the current ontology that represent superclasses to create new classes. This type of coupling can be done though dependency coupling. In contrast to this, García's metrics are focused on the coupling from the point of view of the properties, thus properties define a specific type of internal coupling because they relate classes in the domain of the property with classes in the range of the property, and so these classes are related and coupled by the property. These metrics are focused on providing an insight about the importance of the classes according to their relationships and the way they are related. In total, eleven coupling metrics have been analysed: the number of external classes (NEC), reference to external classes (REC), and referenced includes (RI); and the introduced coupling metrics CBE-out, iCBE-out, CBE-in, iCBE-in, CBE-io, iCBE-io, SC and iSC. The Yang et al. (2006) metrics proposal is intended to reflect the complexity of an ontology during its lifecycle and evolution and they propose three metrics: total numbers of concepts or classes (TNOC), total number of relations (TNOR) and the total number of paths (TNOP). This proposal involves analysing the relations as well as OntoClean or García's coupling metrics. In contrast, Brank et al. (2005) and Lida et al. (2009) proposals are defined to analyse and classify ontologies in diverse categories.

Finally, protégé and ontology metrics tools, basically define the same set of metrics. Just to end it, the García et al. (2010a) proposal is intended to provide a helpful set of metrics to represent the "logical" coupling of classes. For "logical" coupling that means the logical relationship between two concepts in the real world. This

Table 1. Summary of the analysed metrics and comparison of some interesting properties.

Metric	Semantic/structure	Ranking	Cohesion	Coupling
Vrandecic (Vrandecic and Sure, 2007)	Structure	No	No	No
AKTiveRank (Alani et al., 2006)	Structure	Yes	No	No
Orme (Orme et al., 2006)	Structure	No	Yes	Yes
Yinglong (Yinglong et al., 2010)	Semantic	No	Yes	No
OntoClean (Guarino and Welty, 2002)	Semantic	No	No	No
Ontometric (Lozano-Tello and Gómez-Pérez, 2004)	Structure	No	No	No
Protégé (Gennari et al., 2003)	Structure	No	No	No
OntoQA (Tartir et al., 2005)	Structure	Yes	Yes	No
Ontology metrics	Structure	No	No	No
Yang (Yang et al., 2006)	Structure	No	No	No
Lida (Lida et al., 2009)	Structure	No	No	No
Burton-Jones (Burton-Jones et al., 2005)	Structure	No	No	No
Maynard (Maynard et al., 2006)	Structure	No	No	No
García (García et al., 2010a)	Semantic	No	No	Yes

representation is better understood by visualising the concepts and relationships, other than just a simple quantitative value of a metric. CBE metrics are useful for identifying dependencies among classes, as well as those concepts that are more related to others and that most of time represent the main subjects of the ontology. CBE metrics are targeted to the semantics of the ontology, in contrast to those targeted to the structure.

Conclusions

In this paper, diverse ontology metrics and tools have been analysed, most of them are focused on the evaluation of the ontologies structure such as ‘protégé’, ‘ontology metrics’ tool or OntoQA. Other metrics are focused on cohesion such as NoR, NoL, ADIT-LN, NOP, NMIS, AVAI and OntoQA, and there are a few of them focused on coupling such as NEC, REC, RI and CBE proposals. Most of the cohesion metrics are focused on analysing the inconsistencies of an ontology, a relevant aspect to consider in the ontological engineering. On the other hand, this study is focused on the introduced CBE metrics in the semantic meaning of properties as relationships. Each property defines one or more classes in the domain and one or more classes in the range. These classes are related to each other by the property defining a coupling relationship. From this point of view, the declared property would represent a “bridge” between the coupled classes. The coupling relationships are targeted to the semantics of the ontology, in contrast to the “is-a” relationships that are targeted to the hierarchy or taxonomy of concepts. Furthermore, the direction of a property is also important because a class belonging to the domain of a property would not have the same meaning than another class belonging to the range of the property. The analysis of the coupling or relations among classes allows us to discover the most significant classes in the ontology from the point of view of the interaction with other classes. Most of time, the most coupled classes represent the main concepts in the ontology, because they are provided with relations that enrich the model. This work has also described a set of visualisations in order to graphically represent what metrics really mean. This way, this proposal considers that metrics with a semantic background, represent more than a simple quantitative value, and this meaning is better understood using a visual representation, even providing interaction with the user.

Another interesting approach based on ontologies semantics is OntoClean. It defines some metaproperties to analyse and detect not logically consistent relationships. Some metrics have been defined to rank ontologies, to normalise them or to qualify them such as AKTiveRank or ONTOMETRIC. Both approaches are intended to evaluate existing ontologies. ONTOMETRIC is intended to evaluate existing ontologies to order to decide on reusing them, while AKTiveRank evaluates ontologies according to a certain concept and provides us with a ranking order according to the grade of relationship of the ontology with the concept. A completely different approach is proposed by Yang which is based on measuring the complexity of an ontology taking into account the evolution. In this sense, the work presented has provided a metrics classification based on different aspects such as semantics or structure, cohesion, ranking or coupling. In summary, a final conclusion of this work would be to say that it is possible that some metrics have been proposed to cover the diverse aspects being evaluated; most of them focused on the structure instead of semantics. Some of the proposals have not been implemented yet or at least there is not a reference of their implementation. An interesting proposal would be the implementation of the diversity of these metrics in the same tool.

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