Web-Ontology Design Quality Metrics

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Abstract: Semantic Web is an extension of current web in which the web resources are equipped with formal semantics about their interpretation for the machines. These web resources are integrated in the form of web information systems, and their formal semantics are normally represented in the form of web-ontologies. Using the database terminology, we can say that web-ontology of a semantic web system is schema of that system. Since web-ontology is an integral element of semantic web systems, therefore, design quality of a semantic web system can be measured by measuring the quality of its web-ontology. The key consideration is that after completing design of a web-ontology, it is appropriate time to assess its quality so that in case, the design is of low quality, it can be improved before its instantiation. This can save a considerable amount of cost and effort for developing high quality semantic web systems. Metrics are considered as suitable tools for evaluating quality. In this paper, we propose certain metrics for web-ontology quality evaluation. These metrics may contribute in developing a high quality semantic web system. [Journal of American Science. 2010;6(11):52-58]. (ISSN: 1545-1003).

Keywords: Semantic web; Ontology metrics; quality measurement

1. Introduction

Web-ontologies are backbone of a new type of the Web, called the semantic Web. These provide declarative knowledge in a machine processable way. Within the web community, a web-ontology is a formal description of descriptive knowledge of a domain, coded in W3C recommended logic-based languages such as Web Ontology Language (OWL) (Peter et al., 2004). Web-ontologies are an integral part of a semantic web system as schema is an integral part of a database system. It is also obvious that performance of information or knowledge retrieval from semantic web systems depends on the design quality of its ontologies. Therefore, it is very much desirable that the design quality of ontologies should be measured as early as possible during the development of semantic web systems but is very difficult task (Parsia et al., 2005). In our opinion, after completing design of a web-ontology, it is appropriate time to assess its quality so that in case the design is of low quality, it can be improved before its instantiation. This can save a considerable amount of cost and effort for a developing semantic web system of good performance. In this paper, we attempt to achieve this objective and we propose design metrics for ontologies of a semantic web system.

The remainder of this paper is organized as follow. Current status of web-ontology metrics and overview of the related work are given in Section 2. In Section 3, we propose design metrics for a web-ontology, and these metrics are validated in Section 4. Finally, the paper is concluded with recommendations for the future direction in Section 5.

2. Related Work

The AI-community has done a lot of work in the area of ontology as reported in literature such as in (Lozano-Tello et al., 2004), but the web-community has just started work on this area few years ago, especially when the idea of Semantic Web (Lee et al., 2001) was envisioned. Some design metrics for web-ontology have been proposed as reported in literature (Yang et al, 2006; Michael et al., 2005; Burton-Jones et al., 2005), but this area is still in its preliminary stage because little work has been done in this area. Coupling metrics have been suggested for design of web-ontology-based systems (Orme et al., 2006). These metrics are number of external classes, reference to external classes, and referenced includes. It has argued that system quality can be improved if the coupling is measured early in web-ontology-based system's development cycle.

Web-ontology cohesion metrics have been proposed to measure the modular relatedness of web-ontologies (Yao et al., 2005). These metrics compute the number of root classes, number of leaf classes and average depth of inheritance tree (or class-hierarchy). These can be helpful in determining web-ontology structure, its cost estimation and maintenance. These metrics are validated theoretically and also empirically using the validation standards (Briand et al., 1996; Kitchenham et al., 1995).

Semantic metrics, conceptual metrics and web-ontology metrics, for semantic web systems, have been discussed, and compared (Etzkorn, 2006). And it is concluded that more work is needed to validate these metrics in different application areas and their role in the maintenance of those web-ontology-based software systems.

Web-ontology instance metrics have been proposed (Michael et al., 2005). These instance metrics can be used in measuring quantity and importance of data-placement in a web-ontology, and they reflect normalization and efficiency of web-ontology. The instance metrics are further divided into two types which are: knowledgebase metrics, and class metrics. Schema metrics are also proposed for evaluating different characteristics of web-ontology. These schema metrics are relationship-richness, attribute-richness and inheritance- richness metrics. These metrics are used to measure design quality of web-ontology.

As web-ontology is just like knowledge-intensive software therefore all generic metrics for software are also applicable for web-ontology. Some of them are: suitability, accuracy, interoperability, compliance, traceability, understandability, learnability, stability, customizability, user-friendliness, reusability, analyzability, changeability, testability and manageability (Hakkarainen et al., 2005; Korotkiy, 2005; Norman et al., 2003; Paslaru et al., 2005).

In (Baumeister and Seipel, 2005), authors have proposed metrics to measure quality of taxonomy and design of web-ontology. They have focused on inconsistency, incompleteness and redundancy attributes of taxonomy metric and lazy concepts, chains of inheritance, property clumps and lonely disjoints attributes of design metric. While aligning ontologies, the level of similarity among two entities can be measured by metric proposed (Stoilos et al., 2005), in this metric the similarity between two ontologies has been computed, based on their commonalities as well as to their differences.

3. Proposed Design Metrics

In this section we propose design metrics for web-ontology by keeping certain recommended guidelines like a metric may reach its highest value for perfect quality for excellent case and vice versa that is it may reach its lowest level when for worst case. It should be monotonic, clear, and intuitive. It must correlate well with human judgments and it should be automated if possible (King, 2003). The proposed metrics may give information about how much knowledge can be derived from a given web-ontology; how much it is relevant to a user's specific requirements and how much it is easy to reuse, manage, trace and adapt. These metrics are named as *Knowledge Enriched (KnE*), *Characteristics Relevancy (ChR)* and *Domains modularity (DoM).*

3.1 Knowledge Enriched metric

Knowledge Enriched (KnE) metric quantifies the reasoning capability of a web-ontology, and it based on two sub-metrics so-called *Isolated Axiom Enriched* (IAE) metric and *Overlapped Axiom Enriched* (OAE) metric. The axiom mostly consists of three parts: predicate, resource and object. If none of these is common with any other axiom of same domain then that axiom is termed as isolated axiom. Similarly two axioms are said overlapped if those have some common parts. There may be several transitively overlapped axioms in any domain. This metric determines the percentage of IAE and OAE, and if the former is more than the later one, then the web-ontology can be considered less knowledge enriched. IAE is formally defined as the ratio of total number of isolated axioms (tIAs) to the total number of domain axioms (tDAs).

$$IAE = \sum_{i=1}^{n} tIAs \;/\; tDAs$$

$$\text{for all } 1 \le i \le n \text{ ----------- (1)}$$

In Equation (1), *n* is total number of sub-domains of web-ontology. Similarly, the OAE metric is formally defined as ratio of total number of overlapped axioms (tOAs) to the total number of domain axioms. Mathematically it can be written as follows:

$$OAE = \sum_{i=1}^{n} tOA_i \,/\, tDAs$$

$$\text{for all } 1 \le I \le n \text{ ------------------ (2)}$$

In Equation (2), *n* is total number of sub-domains of web-ontology. Finally, the KnE metric is the difference of total number of overlapped axioms and the total number of isolated axioms. Mathematically it may be written as follows:

$$KnE = OAE - IAE \quad \text{---------------- (3)}$$

From equation (1) and equation (2)

In Equation (3) if the resultant value is positive, then the web-ontology is more knowledge enriched, if it is zero, then the web-ontology is average knowledge enriched, and if it is negative, then the web-ontology is less knowledge enriched.

3.2 Characteristics Relevancy metric

Characteristics Relevancy (ChR) metric gives us an idea about how much a given web-ontology is close to a user's specific requirements and the degree of reusability of the web-ontology. Formally, it is defined as the ratio of the number of relevant attributes (nRAs) in a class to the total number of attributes (TnAs) of that class. Mathematically, it is written in Equation (4) as follows:

$$ChR = \sum_{i=1}^{n} nRAs / TnAs$$

$$\text{for all } 1 \le i \le n \text{ …………….. (4)}$$

Where *n* in above equation is the total number of classes in the given web-ontology. ChR metric reveals the percentage of relevant attributes in the web-ontology, and this number gives insights how much a web-ontology is relevant.

3.3 Domain Modularity metric

Domain modularity (DoM) metric measures the component-orientation feature of a web-ontology. This metric indicates the grouping of knowledge in different components of web-ontology. The web-ontology is better manageable, traceable, reusable and adaptable, if it is designed in components (sub-domains). Formally, the DoM metric is defined as the number of sub-domains (NSD) contained in a web-ontology. This metric also depends on the coupling and cohesion levels of sub-domains, and it is directly proportional to its cohesion level and inversely proportional to its coupling level.

$$DoM = NSD + \sum_{i=1}^{n} DCoh_i + 1 / \sum_{i=1}^{n} DCoup_i$$

$$\text{for all } 1 \le i \le n \text{ …………….. (5)}$$

In Equation (5), DCoh represents level of domain cohesion and DCoup represents the level of coupling among sub-domains of web-ontology domain. DoM metric is a real number representing degree of partial reusability of a given web-ontology.

4. Case Study

We have taken a web-ontology of university domain for validating our proposed metrics KnE, ChR and DoM as described in previous sections.

```
<rdf:RDF xmlns="http://www.owl-
ontologies.com/uet-1.owl#"
   xml:base="http://www.owl-ontologies.com/uet-
1.owl"
xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
xmlns:rdfs="http://www.w3.org/2000/01/rdf-
schema#"
xmlns:rdf="http://www.w3.org/1999/02/22-rdf-
syntax-ns#"
xmlns:owl="http://www.w3.org/2002/07/owl#">
  <owl:Ontology rdf:about="">
    <owl:versionInfo rdf:datatype="&xsd;string"
      >Web-ontology for Research Actvity
Management Domain</owl:versionInfo>
    <rdfs:comment
rdf:datatype="&xsd;string"></rdfs:comment>
  </owl:Ontology>
  <owl:Class rdf:ID="Author"/>
  <owl:Class rdf:ID="Director"/>
  <owl:Class rdf:ID="DuptyDirector"/>
  <owl:Class rdf:ID="Faculty">
    <rdfs:subClassOf rdf:resource="#Person"/>
  </owl:Class>
  <owl:DatatypeProperty rdf:ID="hasAffiliation">
    <rdfs:domain rdf:resource="#Researcher"/>
    <rdfs:range rdf:resource="&xsd;string"/>
  </owl:DatatypeProperty>
  <owl:ObjectProperty rdf:ID="hasArea">
    <rdfs:domain rdf:resource="#ResearchGroup"/>
    <rdfs:range rdf:resource="#ResearchArea"/>
  </owl:ObjectProperty>
  <owl:ObjectProperty rdf:ID="hasAuthor">
```

```
          </owl:unionOf>
        </owl:Class>
      </rdfs:domain>
      <rdfs:range rdf:resource="&xsd;string"/>
    </owl:DatatypeProperty>
    <owl:DatatypeProperty rdf:ID="hasId">
      <rdfs:domain>
        <owl:Class>
          <owl:unionOf
rdf:parseType="Collection">
            <owl:Class rdf:about="#Author"/>
            <owl:Class rdf:about="#Director"/>
            <owl:Class
rdf:about="#DuptyDirector"/>
            <owl:Class
rdf:about="#PaperCategory"/>
            <owl:Class rdf:about="#Person"/>
            <owl:Class
rdf:about="#ResearchArea"/>
            <owl:Class rdf:about="#Researcher"/>
            <owl:Class
rdf:about="#ResearchPaper"/>
          </owl:unionOf>
        </owl:Class>
      </rdfs:domain>
      <rdfs:range rdf:resource="&xsd;int"/>
    </owl:DatatypeProperty>
    <owl:DatatypeProperty rdf:ID="hasName">
      <rdfs:domain>
        <owl:Class>
          <owl:unionOf
rdf:parseType="Collection">
```

Figure 1: A Code Slice Of Sample Web-Ontology

First of all we verified its syntactical correctness using w3c validation service. Its RDF graph has show in figure 2. It was found syntactically correct.

KnE - Knowledge Enriched metric

We are working to automate KnE metric, but now it is performed manually. With the help of w3c validation service, we transform web-ontology into list of triples in order to count total axioms, isolated axioms and overlapped axioms present in web-ontology. Its sample is shown in figure 3. There were found 149 total axioms, 96 overlapped axioms and 53 isolated axioms.

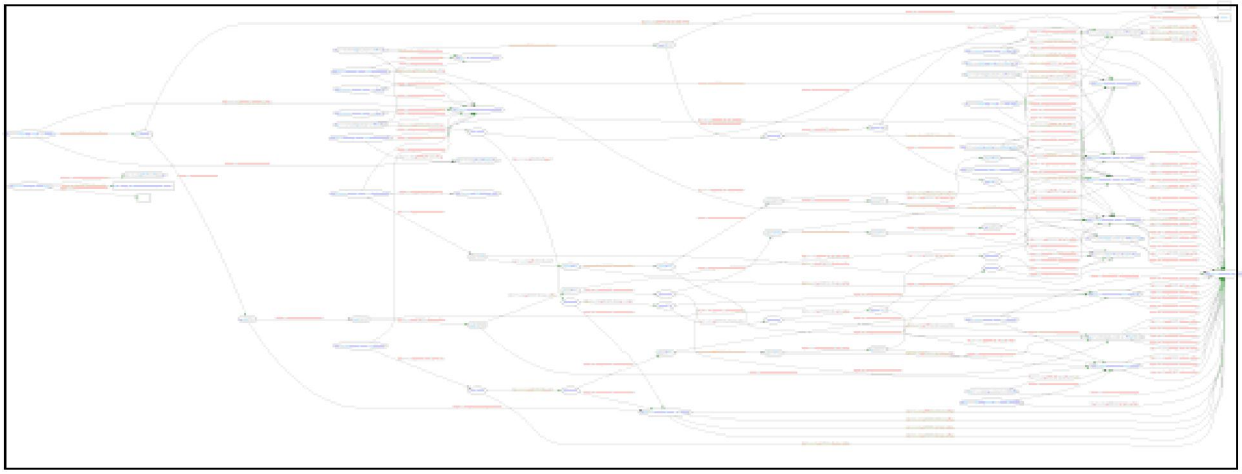

Figure 2: RDF –Graph of Sample Web-Ontology.

N#	Subject	Predicate	Object
1	http://www.owl-ontologies.com/uet-1.owl	http://www.w3.org/1999/02/22-rdf-syntax-ns#type	http://www.w3.org/2002/07/owl#Ontology
2	http://www.owl-ontologies.com/uet-1.owl	http://www.w3.org/2002/07/owl#versionInfo	"Web-ontology for Research Actvity Management Domain"^^http://www.w3.org/2001/XMLSchema#string
3	http://www.owl-ontologies.com/uet-1.owl	http://www.w3.org/2000/01/rdf-schema#comment	""^^http://www.w3.org/2001/XMLSchema#string
4	http://www.owl-ontologies.com/uet-1.owl#Author	http://www.w3.org/1999/02/22-rdf-syntax-ns#type	http://www.w3.org/2002/07/owl#Class
5	http://www.owl-ontologies.com/uet-1.owl#Director	http://www.w3.org/1999/02/22-rdf-syntax-ns#type	http://www.w3.org/2002/07/owl#Class
6	http://www.owl-ontologies.com/uet-1.owl#DuptyDirector	http://www.w3.org/1999/02/22-rdf-syntax-ns#type	http://www.w3.org/2002/07/owl#Class
7	http://www.owl-ontologies.com/uet-1.owl#Faculty	http://www.w3.org/1999/02/22-rdf-syntax-ns#type	http://www.w3.org/2002/07/owl#Class
8	http://www.owl-ontologies.com/uet	http://www.w3.org/2000/01/rdf-	http://www.owl-ontologies.com/uet-1.owl#Person

Figure 3: Partial List of Triples

Although a university ontology is a multi-domain (i.e. there are different sub-domains in university domain) ontology, but this web-ontology file has shown that there is one domain (all sub-domains were merged), this means that n=1 in equation 1.

IAE = 50 / 200 = 0.25, from equation 1.

OAE=150 /200 =0.75

KnE = OAE – IAE

=0.75 – 0.25

= 0.50

This indicates that web-ontology may be considered a knowledge-enriched ontology, with respect to criteria given in section 3.1.

ChR - Characteristics Relevancy metric

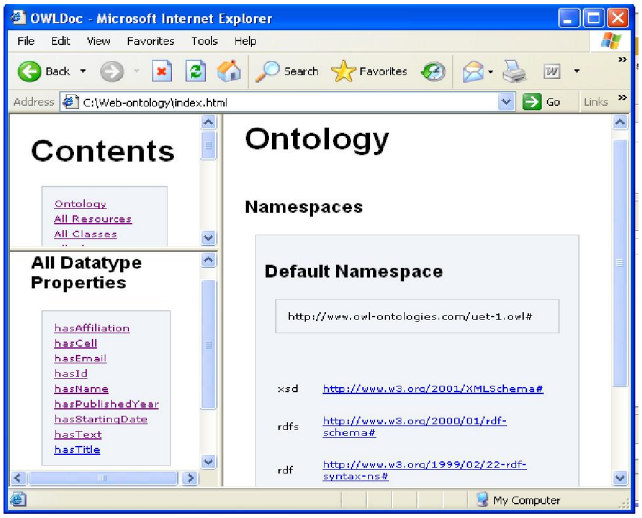

Figure 4: Web-Ontology Document Used For Counting Characteristics

We took a list of requirements from a concerned person from different universities, and then checked web-ontology for how much it was relevant to that user's specific requirements. There were 57 characteristics in the requirement-list, then determined, their presence in the web-ontology using web-ontology documentation, partially shown in figure 3. It was found that there were total 85 characteristics available in web-ontology, and only 22 were found relevant so by formula: ChR = 22 / 85 = 0.26

This means that although available characteristics are more that the required list, but only 26 percents are relevant. It was concluded, that web-ontology is not appropriate for that user's requirements.

DoM - Domain Modularity metric

As we know that a university domain consists of multiple sun-domains. A separate web-ontology should be developed for each sub-domain then integrates all of them to develop a multi-domain ontology. But the sample web-ontology has been developed by merging all sub-domains as we have examined that no web-ontology has imported in sample web-ontology.

This means that whenever we need a web-ontology of any sun-domain of university domain, we have to use complete web-ontology. We have concluded that partial re-usability of the sample web-ontology is very poor. The coupling and cohesion level can be determined by using existing relevant metrics.

```
<?xml version="1.0"?>
<!DOCTYPE rdf:RDF [
  <!ENTITY owl "http://www.w3.org/2002/07/owl#" >
  <!ENTITY xsd "http://www.w3.org/2001/XMLSchema#" >
  <!ENTITY rdfs "http://www.w3.org/2000/01/rdf-schema#" >
  <!ENTITY rdf "http://www.w3.org/1999/02/22-rdf-syntax-ns#" >
]>
<rdf:RDF xmlns="http://www.owl-ontologies.com/uet-1.owl#"
   xml:base="http://www.owl-ontologies.com/uet-1.owl"
   xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
   xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:owl="http://www.w3.org/2002/07/owl#">
  <owl:Ontology rdf:about="">
    <owl:versionInfo rdf:datatype="&xsd;string"
      >a web-ontology for university domain</owl:versionInfo>
    <rdfs:comment rdf:datatype="&xsd;string"></rdfs:comment>
  </owl:Ontology>
  <owl:Class rdf:ID="Author"/>
```

Figure 5: Code Slice Indicating Zero Imported Web-Ontology

5. Theoretical Analysis of Proposed Metrics

In the previous section, we have proposed design metrics for web-ontologies. In this section, we take web-ontology design schema of a university coded in OWL, and evaluate proposed metrics of the web-ontology using the same theoretical standards given in (Kitchenham et al., 1995).

According to (Baumeister and Seipel, 2003), an entity is the item being observed and an attribute is a property of that entity. To measure an attribute-value, its measuring unit should be specified. Measurement scales are nominal, ordinal, interval, or ratio. It has claimed that a valid metric must have validity of attribute, unit, instrument and protocol. Attribute validity states that the entity being evaluated has attributes. Unit validity states that the unit used should be appropriate for the attribute. Instrumental validity states that the underlying model should be valid and the measurement instrument should be regulated. And the protocol validity states that the protocol used for the measurement is consistent, unambiguous and prevents problems. In Short, the concepts necessary to be there in a valid metric are entity, attribute, measuring unit and scale type. A metric satisfying the validity constraints such as attribute validity, unit validity, instrumental validity and protocol validity, is called a valid metric. We have analyzed our metrics against all these constraints.

Analysis of Knowledge Enriched metric

Web-ontology is an entity for proposed metric; the attribute of this metric is the *axiom* to be counted; Unit is *number* of attributes and Data Scale is absolute value. *Attribute validity:* The entity (the web-ontology being analyzed) has number of attributes (isolated and linked axioms). *Unit Validity*: The attribute is measured by counting the number of isolated and linked axioms respectively. *Instrumental Validity:* The instrument is valid as long as the axioms computing tool parse and count the number of isolated and linked axioms respectively. *Protocol Validity*: The computation performed according to equations given in this paper is consistent, unambiguous and error free.

Analysis of Characteristics Relevancy metric

For this metric the *attribute* to be counted, is treated as a concept or entity; *Relevancy* to the user specific needs is an attribute for this metric; unit is *percentage* of correct matches and data scale is *ratio*. *Attribute validity*: The entity (the attribute being analyzed) has attribute (i.e. relevancy).*Unit Validity:* The relevancy is measured by computing percentage of relevant attribute to the user needs. *Instrumental Validity:* We have implemented our model in java modules and it is working correctly, we have also verified it manually. *Protocol Validity*: The formal description of this metric given in this paper is consistent, unambiguous and error free.

Analysis of Domain Modularity metric

Web-ontology is an entity of this metric; attribute of this metric, is *sub-domain* to be counted; Unit is *number* of sub-domains; and Data scale is *absolute value*. *Attribute validity*: The entity (the web-ontology being analyzed) is number of sub-domains used for making the main web-ontology. *Unit Validity:* The sub-domains are counted in numbers. *Instrumental Validity*: We have implemented our algorithm for counting sub-domains, in java modules and it is working correctly, we have also verified it manually. *Protocol Validity:* The equation given in the proposed metric is performing the right calculation.

6. Conclusion and Future Directions

In this paper, we have proposed a set of quality metrics to evaluate design of ontologies. These proposed metrics may be helpful in evaluating design quality of ontologies and improving their design. In this way we may save a considerable amount of development time and cost of good quality semantic web applications. We feel that serious efforts and attentions are needed towards web-ontology design metrics to improve the quality of semantic web applications. It is expected that in the future most software development work will be the development of semantic web applications. By understanding the urgency and importance of this work, we are actively working in this direction.

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5/5/2010