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Evaluating Product Ontologies in E-Commerce: A Semiotic Approach

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Abstract

Product ontologies provide consensual definitions of concepts and inter-relationships between them in a product domain of interest. They aim at solving integration problems in product-related information systems such as e-commerce applications. Assessing to which extent they actually meet user requirements remains a critical question for both ontology engineers and ontology adopters. Current research yields approaches and metrics that originate from the Semantic Web arena; therefore, their scope is constrained by the expressiveness of respective ontology languages such as DAML and OWL. In this paper, we address the evaluation of product ontologies on a broader scale by taking a semiotic perspective. The contribution is that we (1) propose a semiotic set of product ontology metrics that allow for assessing syntactic, semantic, pragmatic, and social quality, and (2) show how these metrics could be used for evaluating a real-world product ontology.

Keywords: Metrics, Ontologies, Quality, Semiotics, Electronic Commerce

1. Introduction

Product-related data is an essential part of many interorganizational information systems, in particular, e-commerce systems. In recent years, product ontologies have attracted both industry and academia because of their potential contribution to solving integration problems in such systems (Shim and Shim 2006). They provide at least to some extent *consensual* definitions of concepts and inter-relationships between these concepts in a product domain of interest. Most product ontologies define a hierarchy of product classes and respective properties for describing product instances. Such ontologies may support finding and comparing products being offered by multiple suppliers and described in distributed data sources, or allow for benchmarking the procurement activities of organizational units (Doring et al. 2006). Ontology users are required to annotate their instance product data accordingly.

Despite the recent emphasis on developing e-commerce applications that greatly rely on product ontologies, there remains relatively little research on approaches for evaluating product ontologies (Lee and Goodwin 2006; Lee et al. 2006). Although such research is clearly important, two factors have made it difficult to conduct research on assessing the quality of product ontologies. First, much of the research has focused on new methodologies, languages, and tools for developing product ontologies. This has made it difficult for researchers to develop generic approaches for evaluating ontological quality that are independent of any one methodology, tool, or language. Second, there is great difficulty in determining what elements of quality to evaluate. In other words, what factors should be considered in evaluating product ontology quality?

Ontology evaluation methods often involve computing scores based on the linguistic information of the ontology. This can be difficult because many class names and property names are some type of merger or combination of two or more words (Malucelli et al. 2006). Having these sets of words as a single name affects the clarity and interpretability, which distorts the ontology quality measure. Another problem involves assessing the overall quality such that it captures all the facets of the quality of the ontology being evaluated. Some aspects that may not be evaluated are: the amount of factual knowledge represented in the ontology; the usefulness of the ontology concepts, and the qualitative information an ontology contains (such as the reviews).

Unfortunately, there is no *de facto* evaluation method that evaluates the quality of most aspects of product ontologies. To do so, a combination of techniques of ontology evaluation and selection must be integrated. For the ontology selection process, research has been carried out to identify metrics, measures, meta-ontologies and inferencing mechanisms that could be used together to improve the generality, applicability and usefulness of ontology evaluation and selection.

Whereas product ontologies emerge in diverse industries and for various tasks, assessing the quality and suitability of a given product ontology, i.e., to what degree it actually meets user requirements, remains a critical question for both ontology engineers and ontology adopters. This question is the focus of ontology evaluation which aims at providing metrics reflecting the ontology's quality and suitability. Current research yields some approaches and metrics for automatically evaluating ontologies (Tatemura and Hsiung 2006). However, these efforts originate from the Semantic Web arena, and therefore rely mainly on the expressiveness of ontology languages such as DAML (DARPA Agent Markup Language) and OWL (Ontology Web Language); hence their scope is constrained by these languages.

In this paper, we address product ontology evaluation on a broader scale by taking a semiotic perspective. Semiotics studies the properties of signs; for our purposes, it can provide a theoretical basis for distinguishing generic categories of quality. We define evaluation metrics based on Stamper et al. (2000) semiotic framework and adopt Burton-Jones' et al. semiotic metrics suite (2005). The contribution is that we: (1) propose a semiotic set of product ontology metrics that allow for assessing syntactic, semantic, pragmatic, and social quality, and (2) show how these metrics could be used for evaluating a real-world product ontology.

The rest of the paper is structured as follows. Section 2 reviews related work. Section 3 presents our set of metrics. In section 4, we discuss the applicability of these metrics. In section 5, we draw conclusions and outline avenues of future research.

2. Related Work

The related work can be grouped into two major areas: product ontologies and ontology evaluation. Despite the former's importance, it is rather a specialized field which attracts interest from communities such as knowledge engineering (e.g., Fensel et al. 2001), data management (e.g., Beneventano et al. 2004), e-commerce (e.g., Leukel 2004), and certainly product data management (e.g., Pierra 2006). While the phrase ‘product ontology’ is often used to stress the formal specification aspect, other widely used terms, though not equal in meaning, are ‘product classification standard’ or ‘product classification system’. The quality and suitability of such artifacts, however, have rarely been the focus of dedicated research. Many researchers take these ontologies for granted and do not further investigate their structure and content.

To the best of our knowledge, only the work by *Hepp et al.* provides product ontology metrics as well as results of extensive quantitative evaluation (Hepp et al. 2005; Hepp et al. 2007). While these metrics analyze product ontologies to a great extent and their rationale reflects a lot of domain expertise, they are confined only to the product ontology. Thus, they do not investigate the relationship between the ontology and, for instance, its users, the ontology language, or other ontologies.

Ontology evaluation in general aims at assessing the relevance of diverse types of ontologies ranging from domain ontologies to upper-level ontologies. There is a growing research community which develops methodologies, models, and tools for ontology evaluation, e.g., EON Workshop Series (Garcia-Castro et al. 2007). Studying the ontological quality is made difficult by a number of factors. Contrary to Information Retrieval, for instance, one can not easily define the metrics ‘precision’ and ‘recall’, since these require a clear set of items – here concepts, inter-relations, and properties – being relevant in the respective domain of interest (Brewster et al. 2004). Ontology evaluation can be classified using multiple attributes, for instance as described in (Hartmann 2004) and (Brank et al. 2005). For the purpose of our work, we focus on one attribute which distinguishes functionality and structure.

The *functionality* of an ontology describes how suitable and appropriate it is for its intended usage in an information system. There are two major approaches. First, one could relate the ontology directly to requirements of the respective task. In this case, such requirements need to be elicited, formalized, and then mapped to elements of the ontology. Second, one could select a particular ontology and compare it to a reference ontology. The shortcoming of both approaches is that both requirements and the reference ontology for the domain of interest can be incomplete, wrong, lacking, and if available, subjective. This is in particular true for broad product ontologies such as UNSPSC[1], eOTD[2] and eCl@ss[3], which all aim at becoming the first reference and global standard, thus comparing them to another reference ontology is not feasible.

The *structure* of an ontology is formed by its elements and inter-relations. A major stream of research is rooted in the Semantic Web arena and its approaches rely on ontology languages such as OWL and its predecessor DAML+OIL. By systematically checking the actual usage of language features such as classes, properties, axioms, instances etc., one can determine the structural characteristics. For instance, complexity metrics are defined in (Yang et al. 2006); they include number of concepts, relations and paths, and mean of relations and paths per concept. Similar metrics can be found in (Huang and Diao 2006) which defines metrics for assessing how balanced a taxonomy is. However, both proposals represent only a limited subset of the entire ontology language features and respective structural aspects.

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[1] http://www.unspsc.org
[2] http://www.eccma.org
[3] http://www.eclass-online.com

A more elaborate set of metrics describing cohesion can be found in (Yao et al. 2005). Based on graph theory, these metrics determine the degree of relatedness of concepts in an ontology. Though mathematically sound, the results of such metrics can not easily be interpreted in terms of quality. The same is true for many structural metrics. For instance, whether a big, nested ontology is better than a smaller one depends widely on the domain of interest. This point of criticism complements the fact that structural metrics in general rely on the expressiveness of ontology languages (thus on what can be described formally). Consequently, these metrics should be regarded as a component of a broader evaluation framework.

The review of related work points out that (1) generic ontology evaluation limits its scope by respective ontology languages and thus can not fully exploit the quality of domain ontologies, in particular product ontologies which rather rely on size and deepness than on formal complexity, and (2) domain ontology evaluation requires not only extensive domain expertise, but also an ontological foundation to arrive at both suitable and well-defined metrics. In the following, we employ semiotics and semiotic metrics to overcome these deficits.

3. Proposed Set of Product Ontology Metrics

In this section, we propose a semiotic set of product ontology metrics based on semiotics and earlier work by Burton-Jones et al. (2005). First, we introduce the semiotic approach to ontology evaluation and define basic metrics. Then we analyze product ontology-specific metrics and relate them to the general semiotic suite.

3.1 Semiotic Metrics Suite

Stamper et al. (2000) present a general theoretical semiotic framework derived from linguistics that includes general elements of quality for evaluating signs. It includes pragmatic issues to develop a metrics suite that is widely applicable yet can be tailored to the needs of specific applications. They provide a 6-level semiotic framework to support the analysis of signs: a) physical, b) empirical, c) syntactic, d) semantic, e) pragmatic, and f) social. There is a dependency relationship between the successive levels, i.e., each level contributes to the next level. Based on these levels, Burton-Jones et al. have developed a metric suite that consists of syntactic, semantic, pragmatic, and social qualities. They do not include physical and empirical quality since they deal with implementation details.

As discussed in (Burton-Jones et al. 2005), the overall quality (Q) of an ontology is computed using a weighted function of its syntactic (S), semantic (E), pragmatic (P), and social (O) qualities (i.e., $Q = b_1 \times S + b_2 \times E + b_3 \times P + b_4 \times O$). The weights sum to unity. In the absence of pre-specified weights, the weights are assumed to be equal. The values for a given ontology will depend on external benchmarks such as the metric's average value across all the ontologies in the ontology library. Since the numerical values of these relative scores could exceed one for any given ontology, the scores for these metrics are normalized so that the values of all metrics vary between zero and one prior to calculating the overall ontological quality. A brief description of each of the metrics is given below.

Syntactic Quality (S) measures the quality of the ontology according to the way it is written. It consists of *Lawfulness,* the degree to which an ontology language's rules have been complied, and *Richness*, the proportion of features in the ontology language that have been used in an ontology.

Semantic Quality (E) evaluates the meaning of terms in the ontology library. Three attributes are used in this metric: interpretability, consistency, and clarity. *Interpretability* refers to the meaning of terms (e.g., classes and properties) in the ontology. *Consistency* is whether terms have a consistent meaning in the ontology. *Clarity* is whether the context of terms is clear. For example, if an ontology claims that class "Chair" has the property "Salary," an application must know that this describes academics, not furniture.

Pragmatic Quality (P) refers to the ontology's usefulness for users, irrespective of syntax or semantics. Three criteria are used for this metric, namely, accuracy, comprehensiveness, and relevance. *Accuracy* is whether the claims an ontology makes are "true." *Comprehensiveness* is a measure of the size of the ontology. Larger ontologies are more likely to be complete representations of their domains, and provide more knowledge to the user. *Relevance* is whether the ontology satisfies the user's specific requirements.

Social quality (O) reflects the fact that users and ontologies exist in communities. It consists of two attributes, namely, authority and history. The *authority* of an ontology is the number of other ontologies that link to it. More authoritative ontologies signal that the knowledge they provide is accurate or useful. The *history* is the number of times the ontology is accessed. It is assumed that ontologies with longer histories are more dependable. Table 1 summarizes the ontology metrics.

Table 1. Ontology Metrics.

Overall Quality (Q)	$Q = b_1 \cdot S + b_2 \cdot E + b_3 \cdot P + b_4 \cdot O$ where: $b_1,..,b_4$ = weights
Syntactic Quality (S)	$S = b_{s1} \cdot SL + b_{s2} \cdot SR$ where: SL = Lawfulness SR = Richness
Semantic Quality (E)	$E = b_{e1} \cdot EI + b_{e2} \cdot EC + b_{e3} \cdot EA$ where: EI = Interpretability EC = Consistency EA = Clarity
Pragmatic Quality (P)	$P = b_{p1} \cdot PO + b_{p2} \cdot PU + b_{p3} \cdot PR$ where: PO = Comprehensiveness PU = Accuracy PR = Relevance
Social Quality (S)	$O = b_{o1} \cdot OT + b_{o2} \cdot OH$ where: OT = Authority OH = History

3.2 Product Ontology-specific Metrics

Evaluating product ontologies requires metrics that address all relevant ontology constructs and respective language features that are used in this type of ontology. In particular, product ontologies rely essentially on providing an often broad and deep hierarchy of product classes (is-a relationships), while other relationship types play a minor role. Product ontology evaluation should investigate the class hierarchy extensively. Therefore, we first define product ontology and then provide respective metrics.

Reviewing current product ontologies and respective conceptual models, we define product ontology PRO as a 5-tuple <PC, RC, PP, RP, PV> where:

- PC: product classes are definitions of product concepts; the class name is augmented with a natural language definition and data management information (e.g., identifiers, version etc.).
- RC: is-a relationships built a hierarchy of product classes; often as a taxonomy with top-level classes (CT) for separating product domains (e.g., automotive, chemical, textile etc.).
- PP: product properties used for describing product instances; in the ontology they serve as a template and are often organized in a dictionary. The definition of a property often includes natural language definition, data type, unit of measurement and other information.
- RP: class-property relationships map properties to classes; the meaning of such a relationship can range from loose recommendations to mandatory.
- PV: enumerated property values besides standard data types such as integer, float and string. Properties can have a list of enumerated values (RV) assigned for expressing a narrower domain, e.g., for colors, shapes, materials etc.

To the best of our knowledge, the most elaborate set of metrics for product ontology evaluation can be found in (Hepp et al. 2007). We select these metrics and convert their definition to our notation of ontology PRO. The result is shown in Table 2 which maintains the set's four aspects of product ontology quality which are (1) amount of ontology content, (2) hierarchical order and balance of scope, (3) class-specific property sets, and (4) ontology growth and maintenance.

3.3 Relation of Product Ontology-specific Metrics to Semiotics

The given metrics cover a broad range of observable, quantitative characteristics of a product ontology. They differ greatly in computational effort required (from counting single items, e.g., M11, to calculating ratios and distribution properties, e.g., M23) and also lead to absolute as well as relative numbers. For integrating these metrics into the semiotic metrics suite, we ask whether and how each metric can contribute to assessing the four qualities as expressed by S, E, P, and O.

The answer is that all metrics determine to some degree the comprehensiveness by measuring the size of the ontology. In particular, metrics M11, M12, and M13 can directly be mapped to PO of P; the metrics M2x and M3x do not just count elements but analyze the distribution and usage of elements across the class hierarchy, thus they provide highly detailed information which refines the general assessments by M11, M12, and M13. M34 and M35, though labeled "semantic", can be mapped to comprehensiveness, too. M41 and M42 measure changes in the ontology over time; this aspect is not covered explicitly by the semiotic metrics suite.

Table 2. Determination of Hepp et al.'s Product Ontology Metrics.

Aspect	Metric	Determination
Amount of content	M11: Number of classes	Number of elements in PC
	M12: Number of properties	Number of elements in PP
	M13: Number of enumerative data type	Number of elements in PV
Hierarchical order and balance of scope	M21: Number of classes per top-level class CT_i	Number of elements in PC which are subclass of CT_i
	M22: Services ratio	(Number of elements in PC representing services) / (number of elements in PC representing goods)
	M23: Distribution properties of metric M21	Minimal value, maximal value, mean, medain, first quartile, third quartile, interquartile range, standard deviation, and coefficient of variation of M21
	M24: Percentage of content in the three biggest top-level classes CT	(Number of subclasses of the three biggest classes CT) / M11
	M25: Size of the biggest top level class vs. median of M21	(Number of subclasses of the biggest class CT) / median of M21
	M26: Number of descendents per subordinate class CO_n	Number of elements in RC with CO_n superclass of CO_m
Class-specific property lists	M31: Specific property lists ratio	(Number of elements in PC with a specific property list in RP) / M11
	M32: Distribution of specific property lists per top-level class CT_i	(Number of elements in PC which are subclass of CT_i and have a specific property list in RP) / M21
	M33: Property usage in property lists	Minimal value, maximal value, mean, median, standard deviation, and coefficient of variation of {number of elements in RP with PP_i}
	M34: Semantic weight of property PP_i	1 / (number of property lists in RP including PP_i)
	M35: Semantic value of property lists	Sum of M34 for each property PP in property list of class PC_i
Growth and maintenance	M41: Number of new classes per month	((Number of elements in PC in the current version of PRO) – (number of elements in PC in the former version of PRO)) / (number of months between publication of the current and former version of PRO)
	M42: number of new classes per top-level class CT_i	M41 for CT_i

4. Discussion

This section provides a brief discussion of the applicability of the proposed metrics. For this purpose, we select the eClassOWL[4], a real-world product ontology. Since eClassOWL has been derived from the international product classification standard eCl@ss, it provides a huge amount of product knowledge (Hepp 2006). Applicability addresses the question, how the proposed semiotic metrics can be used for assessing such a product ontology. Therefore, we discuss each quality aspect and the respective metrics:

Syntactic quality:

- Lawfulness (SL): eClassOWL is syntactically correct and has been checked formally by respective OWL tools. Many other product ontologies, however, come as databases or spreadsheet files; hence have a less strict formal specification.
- Richness (SR): eClassOWL rather uses few OWL language features (missing, e.g., unionOf, intersectionOf, inverseOf). For OWL ontologies, richness can easily be assessed by software tools such as Protégé.

Semantic quality:

- Interpretability (EI): The meaning of terms used in eClassOWL can be checked by searching for entries in a reference dictionary (e.g., WordNet). We assume that in specific product domains (e.g., chemical domain), the share of equal terms is lower than in broader ontologies.
- Consistency (EC): Inconsistencies in product ontologies can occur if is-a relationships are used falsely; here, cross-checks with WordNet could help identifying those.
- Clarity (EA): When interpreting terms in eClassOWL at the lowest level of the taxonomy, the scope or context defined by super classes and the top-level class should be considered.

Pragmatic quality:

- Comprehensiveness (PO): The product ontology metrics given in section 3.2 can be applied to eClassOWL and other product taxonomies, since they are designed for this domain.
- Accuracy (PU): Whether a claim made in eClassOWL is true or false can only be determined by domain experts. In general, reasoning, could help, though most product ontologies provide only is-a relationships and few other relationships or axioms.
- Relevance (PR): Whether a product ontology provides the knowledge required by an application could at least partly be answered by querying the ontology.

Social quality:

- Authority (OT): Other ontologies that link to eClassOWL could be identified by querying ontology repositories or the Web.
- History (OH): Accesses to eClassOWL could be recorded by the ontology provider. However, since product ontologies are often used in non-public business applications, their actual usage and acceptance can hardly be determined.

5. Conclusion

A large number of ontologies are available on the web and many more are being added every day. However, finding a suitable ontology for a particular task is non-trivial because these ontologies are implemented using a variety of languages, methodologies and platforms. Product ontologies are heavily used in product engineering applications as well as e-commerce systems. Assessing

[4] http://www.heppnetz.de/projects/eclassowl

their quality and selecting a particular ontology is difficult because of the heterogeneity. We have presented a semantic set of product ontology metrics that allow for assessing the syntactic, semantic, pragmatic, and social quality, and showed how these metrics could be used for evaluating a real-world product ontology. This metric suite can be used by applications to assess the quality of available ontologies in a domain and dynamically select an appropriate ontology to use. The semiotics based approach sheds light on creating various categories of quality and provides a systematic way to develop quality metrics.

This research contributes in advancing the state of the art in ontology reuse. Considerable effort goes into creating product ontologies and they should be easily accessible for performing various tasks related to e-commerce on the Web. In order for e-commerce to flourish, applications have to be able to find good quality product ontologies on the fly. Although some effort has gone into proposing evaluation criteria for product ontology quality and effectiveness, they seem somewhat premature. Existing tools do not adequately support ontology searching and selection. Our proposed methodology provides a framework for easy identification and evaluation of appropriate product ontologies for supporting seamless e-commerce activities.

Our proposed product ontology evaluation approach has some limitations. First, it does not include application-specific evaluation of the quality of the elements in the ontology for use in a particular e-commerce task. Second, it does not include any learning mechanism to update the evaluations based upon feedback from external users. Third, it does not provide explicit guidelines for determining the optimal weighting scheme. Finally, empirical testing of the approach is needed to validate the relationship between an ontology's internal attributes reflected in its metrics and its external attributes such as its usefulness for supporting an application

Our future work involves applying our metrics suite to evaluate, e.g., eCl@ssOWL, developing a tool for automated ontology quality assessment and applying it to ontologies in other domains. Ontologies evolve over time and the metric suite should take into account this dynamic nature (Hepp 2007). The experience gained in ontology quality assessment will lead to designing better ontologies.

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