Ontology Selection for Reuse: Will It Ever Get Easier?

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Abstract: Ontologists and knowledge engineers tend to examine different aspects of ontologies when assessing their suitability for reuse. However, most of the evaluation metrics and frameworks introduced in the literature are based on a limited set of internal characteristics of ontologies and dismiss how the community uses and evaluates them. This paper used a survey questionnaire to explore, clarify and also confirm the importance of the set of quality related metrics previously found in the literature and an interview study. According to the 157 responses collected from ontologists and knowledge engineers, the process of ontology selection for reuse depends on different social and community related metrics and metadata. We believe that the findings of this research can contribute to facilitating the process of selecting an ontology for reuse.

1 INTRODUCTION

Ontology reuse, using an existing ontology as the basis for building new a one, is beneficial to the community of ontologists and knowledge engineers. It will help in achieving one of the primary goals of ontology construction, that is to share and reuse them (Simperl, 2009), and will also save a significant amount of time and financial resources. Despite all the advantages of ontology reuse and the availability of different ontologies, it has always been a challenging task (Uschold et al., 1998). Ontology reuse consists of different steps namely searching for adequate ontologies, evaluating the quality and fitness of those ontologies for the reuse purpose, selecting an ontology and integrating it in the current project (d'Aquin et al., 2008). Some consider the first steps of this process, which is evaluation and selection of the knowledge sources that can be useful for an application domain (Bontas, Mochol and Tolksdorf, 2005), as the hardest step of this process (Butt, Haller and Xie, 2014).

Ontology evaluation is at the heart of ontology selection and has received a considerable amount of attention in the literature. Gómez-Pérez (1995) defines the term evaluation as the process of judging different technical aspects of an ontology namely its definitions, documentation and software environment. Evaluation has also been described as the process of measuring the suitability and the quality of an ontology for a specific goal or in a specific application (Fernández, Cantador and Castells, 2006). This definition refers to the approaches that aim to identify an ontology, an ontology module or a set of ontologies that satisfy a particular set of selection requirements (Sabou et al., 2006).

This study aims to determine some of the metrics that can be used to evaluate the suitability of an ontology for reuse. The fundamental research question of this study was whether or not social and community related metrics can be used in the evaluation process. Another question was how important those metrics were compared to the well-known ontological metrics such as content and structure. Qualitative and quantitative research designs were adopted to provide a deeper understanding of how ontologists and knowledge engineers evaluate and select ontologies. This study offers some valuable insights into ontology quality, what it depends on and how it can be measured.

2 BACKGROUNDS

Since 1995 to date, there has been a variety of research on different aspects of ontology evaluation including methodologies, tools, frameworks, methods, metrics, measures, etc. However, much uncertainty and also disagreement still exists about the best way to evaluate an ontology generally or for a specific tool or application. As it is seen in the literature, there are many different ways of evaluating ontologies and also many ways of classifying those evaluation methods, algorithms and

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approaches. This section aims to review and classify some of the most popular ontology evaluation approaches.

Ontology evaluation approaches can broadly be classified as follow:

User-based Evaluation (Hlomani and Stacey, 2014) : also known as metric based or feature based; ontologists and knowledge experts can assess the quality of ontologies by comparing them against a set of pre-defined criteria (Maiga and Ddembe, 2008) or by analysing the reviews and comments provided by their peers on different aspects of ontologies (Supekar, 2005).

Golden Standard: refers to the type of evaluation that is performed by comparing an ontology to another ontology, also known as a "gold standard" ontology, and aims to find different types of similarities between them, e.g. lexical, conceptual, etc. This approach was first proposed by Maedche and Staab (2002) and was then used in other research, namely Brank, Mladenic and Grobelnik (2006).

Task-based Evaluation: also known as application-based (Fahad and Qadir, 2008) or black box evaluation (Obrst et al., 2007); aims to evaluate an ontology's performance in the context of an application (Brewster et al., 2004). According to this approach, there is a direct link between the quality of an ontology and how well it serves its purpose as a part of a broader application (Netzer et al., 2009).

Data or Corpus Driven Evaluation: this approach is similar to the "gold standard" approach, but instead of comparing an ontology to another ontology, it compares it to a source of data or a collection of documents (Brank, Grobelnik and Mladenic, 2005). One of the most popular architectures for this type of evaluation is proposed by Brewster et al. (2004).

Rule-based (logical): this type of evaluation is proposed by (Arpinar, Giriloganathan and Aleman-Meza, 2006) and aims to validate ontologies and detects conflicts in them by using different rules that are either a part of the ontology development language or are identified by users.

From all the approaches mentioned above, much of the research in the ontology evaluation domain has concentrated on criteria-based approaches, and many have tried to identify and introduce a set of metrics that can be used for ontology evaluation. A more detailed account of criteria-based ontology evaluation is given in the next section.

3 CRITERIA-BASED EVALUATION

According to a study conducted by Talebpour, Sykora and Jackson (2017), quality metrics for ontology evaluation can broadly be classified into three main groups: (1) Internal metrics that are based on different internal characteristic of ontologies such as their content and structure, (2) Metadata related metrics that can be used to describe ontologies and to help in the selection process, and (3) Social metrics that focus on how ontologies are used by communities.

3.1 Internal Metrics

Internal aspects of ontologies have always been used as a mean of their evaluation. Different internal quality criteria such as clarity, correctness, consistency, completeness, etc. have been used in the literature to measure how clear ontology definitions are, how different entities in an ontology represent the real world, how consistent an ontology is, and how complete an ontology is (Yu, Thom and Tam, 2009). Coverage is yet another significant content related metric; the term coverage is mostly used in the literature to measure how well a candidate ontology match or cover the query term(s) and selection requirements (Buitelaar, Eigner and Declerck, 2004). Structure or graph structure (Gangemi et al., 2006) is the other important internal aspect of an ontology that can be used to measure how detailed the knowledge structure of an ontology is (Fernández et al., 2009) and also to evaluate its richness of knowledge (Sabou et al., 2006), density (Yu, Thom and Tam, 2007), depth and breadth (Fernández et al., 2009), etc.

3.2 Metadata

Besides the internal aspects of ontologies, some of the frameworks and tools have suggested evaluating ontologies using different types of metadata. Metadata or "data about data" is widely used on the web for different reasons namely to help in the process of resource discovery (Gill, 2008). Sowa (2000) believes that the primary connection between different elements of an ontology is in the mind of the people who interpret it; so, tagging an ontology with more data will help in making those mental connections explicit. Ontologies can be tagged and described according to their different characteristics, e.g. size, type, version, etc. The language that different ontologies are built and implemented with can also be used as a metric to evaluate, filter and

categorise them (Lozano-Tello and Gómez-Pérez, 2004).

There are different examples of using metadata in the literature to help with the process of evaluating, finding and reusing ontologies. Swoogle (Ding et al., 2004) was one of the very first selection systems in ontology engineering field to introduce the concept of metadata to this domain. There is a metadata generator component in this system that is responsible for creating and storing three different types of metadata about each discovered ontology including basic, relation, and analytical metadata (ibid.). Supekar (2005) have also proposed two sets of metadata that can be used to evaluate ontologies: source metadata and third-party metadata.

Moreover, metadata is created and used to help interoperability between different applications and ontologies. Ontology Metadata Vocabulary (OMV) was proposed by Hartmann at al. (2005) and is one of the most popular sets of metadata for ontologies. OMV is not directly concerned with ontology evaluation or ranking and its main aim is to facilitate ontology reuse. Matentzoglu et al. (2018) have proposed a guideline for minimum information for the reporting of an ontology (MIRO) to help ontologists and knowledge engineers in the process of reporting ontology description and providing documentation. It is believed that MIRO can improve the quality and consistency of ontology descriptions and documentation.

3.3 Community Aspects of Ontologies

How ontologies are used by communities can be used as a metric in the evaluation and selection process. Hlomani and Stacey (2014) define user-based ontology evaluation as the process of evaluating an ontology though users' experiences and by capturing different subjective information about ontologies. According to a study that was conducted by Lewen and d'Aquin (2010), relying on the experiences of other users for evaluating ontologies will lessen the efforts needed to assess an ontology and reduce the problems that users face while selecting an ontology. Mcdaniel, Storey and Sugumaran (2016) have also highlighted the importance of relying on the wisdom of the crowd in ontology evaluation and believe that improving the overall quality of ontological content on the web is a shared responsibility within a community.

Several studies have attempted to investigate and explore how community and social aspects of ontologies can affect their quality. According to an interview study conducted by Talebpour, Sykora and Jackson (2017), knowledge engineers consider different social aspects of ontologies when evaluating them. Those aspects include: (1) build related information, for example, who has built the ontology, why the ontology was built, do they know the developer team, (2) regularity of update and maintenance, and (3) responsiveness of the ontology developer and maintenance team and their flexibility and willingness toward making changes.

Another popular approach was proposed by Burton-Jones et al. (2005) where a deductive method was applied to identify a set of general, domain-independent and application-independent quality metrics for ontology evaluation. This approach proposed different social quality metrics namely authority and history to measure the role of community in ontology quality. Another example of social based quality application was proposed by Lewen et al. (2006) in which the notion of the open rating system and democratic ranking were applied to ontology evaluation. According to this approach, users of this system can not only review the ontology, but they can also review the reviews provided by other users about an ontology. A similar approach was proposed by Lewen and d'Aquin (2010) where users' ratings are used to determine what they call user-perceived quality of ontologies.

Overall, the above-mentioned studies highlight the importance of the criteria-based approaches in ontology evaluation. They also outline the most important or used quality metrics in the literature. The next sections discuss the methodology used to collect data and the findings of this research.

4 METHODOLOGY

From all the groups of quality related metrics mentioned in the previous section, the focus of this research is on different metadata and social characteristics of ontologies that can be used in the evaluation process. This study was built upon the findings of the previous interview study conducted by Talebpour, Sykora and Jackson (2017) and aims to clarify and confirm the metrics identified in that study. To do that a survey questionnaire was designed based on a mixed research strategy combining qualitative and quantitative questions.

The survey was sent to a broad community of ontologists and knowledge engineers in different domains. Different sampling strategies namely purposive sampling (Morse, 2016) were used in order to find the ontologists and knowledge engineers that were involved in the process of ontology development and reuse. The survey was also forwarded to different active mailing lists in the field of ontology engineering. The lists used are as follows:

- The UK Ontology Network

- GO-Discuss
- DBpedia-discussion
- The Protégé User
- FGED-discuss
- Linked Data for Language Technology Community Group
- Best Practices for Multilingual Linked Open Data Community Group
- Ontology-Lexica Community Group
- Linking Open Data project
- Ontology Lookup Service announce
- Technical discussion of the OWL Working Group
- This is the mailing list for the Semantic Web Health Care and Life Sciences Community Group

There was a total number of 31 questions broadly divided into four different sections. Each section consisted of different number of questions and aimed to explore and discover the opinion of ontologists and knowledge engineers regarding (1) the process of ontology development, (2) ontology reuse, (3) ontology evaluation and the quality metrics used in that process, and (4) the role of community in ontology development, evaluation and reuse. Different types of questions were used in the survey namely close-ended questions, Likert scale questions, open-ended questions, and multiple-choice questions. Screening questions were also used throughout the survey to make sure that respondents are presented with the set of questions that is relevant to their previous experiences.

The most important part of the survey aimed to explore the process of ontology evaluation and the set of criteria that can be used in this process. Respondents were first asked about the approaches and metrics they tend to consider while evaluating ontologies. They were then presented with four different sets of quality metrics including (1) internal, (2) metadata, (3) community and (4) popularity related criteria and were asked how important they thought those metrics were, by offering a 5-point Likert scale, ranging from "Not important" to "Very important". The criteria presented and assessed in this part of the survey were collected both from the literature and the previous phase of the data collection, that was an interview study with 15 ontologists and knowledge engineers in different domains (Talebpour, Sykora and Jackson, 2017).

5 FINDINGS

As was mentioned in the previous sections, this research aimed to introduce different metrics that could be potentially used for ontology evaluation. Prior studies have identified many different quality metrics, mostly based on ontological and internal aspects of ontologies. This study was designed to determine the importance of those metrics and also to explore how communities can help in the selection process. The findings of this study are discussed in the following sections.

5.1 Demographics of Respondents

This study managed to access ontologists and knowledge engineers with many years of experience in building and reusing ontologies in different domains. Around 80% of the participants in the survey were actively involved in the ontology development process and all of them would consider reusing existing ontologies before building a new one. The 157 respondents of this study are categorised by the following demographics, all declared by responders:

Job Title: After conducting frequency analysis on the job titles provided by respondents, 78 unique job titles were identified, many of which were somehow related to different roles and positions in academia such as researcher, professor, lecturer, etc.

Type of Organisation: According to the frequency analysis conducted on the organisation types, 68.8% (108) of the respondents of the survey were working in academia. The other 31.2% of the respondents were working in other types of organisations including different companies and industries.

Years of Experience: Interestingly, most of the survey respondents were experts in their domain and only around 10% of them had less than two years of experience. Around 46% (73) of the respondents had more than ten years of experience. The second largest group of the respondents were the ontologists with five to ten years of experience (26.8%).

Main Domains They Had Built or Reused Ontologies In: survey respondents had worked/were working in many different domains such as biomedical, industry, business, etc. Most of participants had mentioned more than one domain, some of which were not related to each other.

5.2 Evaluation Metrics According to Qualitative Data

Before presenting participants with four sets of quality metrics that can be used for ontology evaluation and asking them to rate those metrics, they were asked an open-ended question about how they evaluate the quality of an ontology before selecting it for reuse. This question aimed to provide

further insight and to gather respondents' opinions on different evaluation metrics and approaches. The responses to this question were coded according to different categories of quality metrics namely (1) internal, (2) metadata, (3) community and popularity related metrics.

According to the analysis, quality metrics thought to be the most important were content and coverage (mentioned 51 times) and documentation (mentioned 41 times). The fact that an ontology has been reused previously and the popularity of the ontology on the web, or among community was the other frequently mentioned metric by the respondents (38 times). Community related metrics such as reviews about the quality of an ontology, existence, activeness and responsiveness of the developer team, and the reputation of the developer team or organisation responsible for ontology were also mentioned by many of the respondents (25 times).

The findings of the qualitative question in the survey confirmed the findings of the quantitative part and the interview study previously conducted by Talebpour, Sykora and Jackson (2017). It should be noted that two of the metrics mentioned by the responders namely "fit" and "format" were not presented as a Likert item in the quantitative part of the survey. Format was only mentioned two times but how relevant an ontology is to an application requirement was mentioned 37 times. The reason fit was not used as a Likert item is that it cannot be used as a criterion to judge the quality of an ontology. However, it is a significant factor in the selection process.

One of the emerging themes in the analysis was "following or being a part of a standard". Interestingly, 19 respondents had mentioned following or complying with different design guidelines and principles or being a part of a standard like W3C, and OBO Foundry as a criterion in the evaluation process. Some had also mentioned that while evaluating an ontology, they check if it is built by using a method like NEON. A similar question was proposed as one of the Likert items and respondents were asked to rate how important "The use of a method /methodology (e.g. NEON, METHONTOLOGY, or any other standard and development practice)" is when evaluating an ontology. Surprisingly, it was ranked 30th (out of 31) with a mean of 2.80 and a median of 3.

5.3 Importance of Quality Metrics

Table 1 shows the descriptive statistics of all 31 quality metrics, sorted by standard deviation. The metrics are ranked from 1 to 31, with 1 being the most important and 31 being the least important metric considered when evaluating the quality of an ontology for reuse. Mean and median are used to show the centre and midpoint of the data respectively. Standard deviation is used to express the level of agreement on the importance of each metric in the ontology evaluation process; the lower value of standard deviation represents the higher level of agreement among the survey respondents on a rating.

As it is seen in Table 1, ontology content including its classes, properties, relationships, individuals and axioms is the first thing ontologists and knowledge engineers tend to look at when evaluating the quality of an ontology for reuse. Other internal aspects of ontologies like their structure (class hierarchy or taxonomy), scope (domain coverage), syntactic correctness, and consistency (e.g. naming and spelling consistency all over the ontology) are also among the top ten quality metrics used for ontology evaluation.

According to Table 1, Documentation is the second most important quality metric used in the evaluation process. Survey respondents have also given a very high rate, five and eight respectively, to other metadata related metrics such as accessibility and availability of metadata and provenance information about an ontology. In contrast to the these metrics, other criteria in the metadata group like availability of funds for ontology update and maintenance, use of a method/methodology and ontology language are among the bottom ten least important metrics.

Community related metrics have some very interesting ratings. The results show ontologists and knowledge engineers would like to know about the purpose that an ontology is used/has been used for (e.g. annotation, sharing data, etc.) while evaluating and before selecting it for reuse. They have also rated "Availability of wikis, forums, mailing lists and support team for the ontology" as one of the very important quality metrics for ontology evaluation. Having an active, responsive developer community and knowing and trusting the ontology developers are among the other top-ranked community related aspects of ontologies that can be used for their evaluation.

Survey responders were also presented with a set of popularity related metrics. According to Table 1, the popularity of an ontology in the community and among colleagues has the highest median and mean compared to the other metrics that can be used for evaluating the popularity of an ontology. Respondents also tended to consider the reputation of the ontology developer team and/or institute in the domain while evaluating an ontology for reuse. Other popularity related metrics such as the popularity of the ontology in social media (e.g. in

Table 1: Descriptive statistics of all the quality metrics in the survey.

Rank	Metric	SD	Median	Mean
1	The Content (classes, properties, relationships, individuals, axioms)	0.57	5	4.59
2	The availability of documentation (both internal, e.g. adding comments and external)	0.79	5	4.38
3	The Structure (Class hierarchy or taxonomy)	0.82	4	4.29
4	The Scope (domain coverage)	0.84	5	4.42
5	The ontology is online, accessible, and open to reuse (e.g. License type)	0.85	5	4.52
6	The Syntactic Correctness	0.92	4	4.15
7	The Consistency (e.g. Naming and spelling consistency all over the ontology)	1.00	4	4.03
8	Availability of metadata and provenance information about the ontology	1.01	4	3.92
9	Availability of wikis, forums, mailing lists and support team for the ontology	1.03	4	3.45
10	Having information about the purpose that ontology is used/has been used for (e.g. annotation, sharing data, etc.)	1.03	4	3.77
11	The Semantic Richness and Correctness (e.g. level of details)	1.06	4	3.92
12	Having an active responsive (developer) community	1.09	4	3.62
13	Having information about the other individuals or organisations who are using/have used the ontology	1.1	3	3.12
14	Having information about the other projects that the ontology is used/has been used in	1.1	3	3.34
15	Knowing and trusting the ontology developers	1.11	4	3.42
16	Knowing and trusting the organisation or institute that is responsible for ontology development	1.11	3	3.38
17	The reputation of the ontology developer team, and/or institute in the domain	1.12	3	3.31
18	The number of times the ontology has been reused or cited (e.g. owl:imports, rdfs:seeAlso, daml:sameClassAs)	1.13	3	3.40
19	The flexibility of the Ontology (being easy to change) and the ontology developer team	1.14	4	3.41
20	The frequency of updates, maintenance, and submissions to the ontology	1.16	3	3.22
21	The popularity of the ontology in social media (e.g. in GitHub, Twitter, or LinkedIn)	1.16	2	2.28
22	The popularity of the ontology in the community and among colleagues	1.17	4	3.51
23	The number of updates, maintenance, and submissions to the ontology	1.19	3	3.13
24	Availability of published(scientific) work about the ontology	1.19	4	3.56
25	The size of the ontology	1.19	3	3.02
26	The number of times the ontology has been reused or cited (e.g. owl:imports, rdfs:seeAlso, daml:sameClassAs)	1.19	3	3.08
27	The availability of funds for ontology update and maintenance	1.23	3	2.77
28	The popularity of the ontology on the web (number of times it has been viewed in different websites/applications across the web)	1.24	3	3.05
29	The reviews of the ontology (e.g. ratings)	1.25	3	3.03
30	The use of a method /methodology (e.g. NEON, METHONTOLOGY, or any other standard and development practice)	1.26	3	2.80
31	The Language that ontology is built in (e.g. OWL)	1.30	4	3.70

GitHub, Twitter, or LinkedIn), the popularity of the ontology on the web (number of times it has been viewed in different websites/applications across the web), and the reviews of the ontology (e.g. ratings), were among the metrics with the least mean and median.

6 DISCUSSIONS

Finding a set of metrics that can be used for evaluating ontologies and their subsequent selection for reuse has always been a critical research topic in the field of ontology engineering. As mentioned in the introduction and background sections, many different ontology evaluation approaches and

metrics for quality assessment have been proposed in the literature, with the aim of facilitating the process of ontology selection. However, these studies have not dealt with ranking and the importance of the quality metrics, especially the community related ones. The focus of this research was on constructing a criteria-based evaluation approach and determining a set of metrics that ontologists and knowledge engineers tend to look at before selecting an ontology for reuse. This study also set out with the aim of assessing the importance of the quality metrics identified in the literature and in a previous phase of this research (Talebpour, Sykora and Jackson, 2017).

Past studies have mostly been concerned with identification and application of a new set of quality metrics (Lozano-Tello and Gomez-Perez, 2004). However, the key aim of this study was not only to identify the main quality metrics used in the process of evaluating ontologies but also to find how important each of the quality metrics are. The results of this survey study indicate that the internal characteristics of ontologies are the first to assess before selecting them for reuse. However, some other aspects of ontologies such as availability of documentation, availability and accessibility of an ontology (e.g. license type), availability of metadata and provenance information, and also having information about the purpose that ontology is used/has been used for previously (e.g. annotation, sharing data, etc.) are as important as the quality of the internal components of ontologies.

Popularity is the most defined and used term in the literature to refer to the role of community in the quality assessment process. As a part of this study, respondents were asked to rate the importance of six different popularity related metrics, four of which were previously mentioned in the literature. According to the results, ontologists and knowledge engineers tend to care more about the popularity metrics, as identified by Talebpour, Sykora and Jackson (2017), such as popularity of an ontology in the community and among colleagues (ranked 14 out of 31, when sorted by median) and the reputation of the ontology developer team, and/or institute in the domain (ranked 21 out of 31, when sorted by median) than the popularity related metrics that have been widely used in the literature and by selection systems. Metrics used in the literature include the number of times an ontology has been reused or cited (Supekar, Patel and Lee, 2004; Wang, Guo and Fang, 2008), the popularity of an ontology on the web (Burton-Jones et al., 2005; Martinez-Romero et al., 2017), the reviews of an ontology (Lewen and d'Aquin, 2010) and the popularity of an ontology on social media (Martínez-Romero et al., 2014); while having a lower median and mean, some of these metrics were ranked higher when the quality metrics were sorted by standard deviation. Standard Deviation shows a higher level of agreement among the survey respondents about the lower rank of those metrics.

7 CONCLUSIONS

The primary aim of this paper was to identify a set of metrics that ontologists and knowledge engineers tend to consider when assessing the quality of ontologies for reuse. The results of this survey study found that the process of ontology evaluation for reuse does not only depend on the internal components of ontologies, but it also depends on many other metadata and community related metrics. This study identified different criteria that can be used for ontology evaluation, and also measured how important those criteria were. Taken together, the results suggest that the metadata and social related metrics should be used by different selection systems in this field, in order to facilitate ontology discovery and to provide a more comprehensive and accurate recommendation for reuse.

These findings enhance our understanding of the notion of ontology quality and the key features ontologists and knowledge engineers look for when reusing ontologies. This research can aid ontology developers as it provides them with key metrics which they could take into consideration when developing a new ontology to enhance its longevity and to provide better foundations to the ontology community for future developments. Further research could explore if the choice of quality metric for ontology evaluation varies from domain to domain.

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