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Evaluation Metrics for Computer Science Domain Specific Ontology in Semantic Web Based IRSCSD System

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Abstract

Performance and efficiency of web information retrieval is important for knowledge engineers, novice users and for organizations. In semantic web based system, the concept of ontology is used to search results by contextual meaning of input query instead of keyword matching. Ontology is an approximate specification of a domain whereas ontology evaluation is concerned with the degree or rather the distance between this approximate conceptualization and the real world. For this, ontology based information retrieval system for computer science domain is designed which this research calls as the IRSCSD system. This paper considers the evaluation of prototype ontology developed in computer science domain for IRSCSD system and has four- fold objectives. Firstly, paper highlights the high level design of IRSCSD system (Information retrieval system for computer science domain). Secondly, paper discusses the prototype ontology developed for computer science domain taking one of its core subjects. Thirdly, paper focuses on the need for evaluation of ontology and various approaches, metrics which can be used for evaluation of domain specific ontology in computer science. Lastly, implementation will be shown by considering those approaches on prototype ontology along with the data sets used for evaluation.

Keywords: Semantic web; Information retrieval; Ontology quality; Ontology evaluation; Evaluation metrics; Ontology verification; Ontology validation; Sparql queries; Jena fuseki.

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1. Introduction

Semantic web which is an intelligent and meaningful web is new web architecture [1]. Ontology is used as a structure for capturing knowledge about certain domain by providing relevant concepts and relations between them. Ontology provides a knowledge-sharing framework that supports the representation and sharing of

domain knowledge [2].Ontology in computer science is a way of representing a common understanding of a domain. It allows for machine-understandable semantics of data, and facilitates the search, exchange, and integration of knowledge. Ontology is different from traditional keyword-based search engines in that they are metadata, able to provide the search engine with the functionality of semantic matching. Ontology is able to search more efficiently than traditional methods [3].

A key factor which makes a particular discipline or approach scientific is the ability to evaluate and compare the ideas within the area. The same holds also for semantic web research area when dealing with abstractions in the form of ontology [4]. The ontology's ability to capture the content of the universe of discourse at the appropriate level of granularity and precision and offer the application understandable correct information are important features that are addressed in many ontology quality frameworks. So, ontology evaluation is a complex and time-consuming process [5].

In this research paper, evaluation of prototype ontology developed in computer science domain has been considered. Paper is structured as follows. Firstly, layout of IRSCSD system will be discussed covering high level design. Secondly, methodology for prototype ontology developed in computer science domain and tools used for the same is mentioned. Thirdly, this research paper highlights all the approaches and metrics for ontology evaluation. Lastly, elaboration of those approaches by implementing them on prototype ontology developed and results are presented and discussed. Finally, paper ends with conclusion and outlines the future work.

2. Semantic Web Based IRSCSD System

This IRSCSD system for information retrieval system in computer science domain will be user friendly as its interface will accept natural language queries to extract data from domain specific ontology and retrieve the desired results. There is no need of learning SPARQL language for retrieving data from RDF/OWL based database. Ontology is a RDF/OWL based database whose query language is SPARQL, so there is a need of conversion from natural language query to SPARQL query to retrieve data from Ontology. In this system, input query in natural language is converted into a SPARQL query which is a query language for RDF based database. SPARQL query is then fired on to the RDF database and accesses the relevant information. Thus, the semantic web based IRSCSD architecture is comprised of three main phases: Ontology building, NLQ to SPARQL Conversion, running SPARQL query on Ontology and fetching desired results. High level design of IRSCSD system is shown below in figure 1.

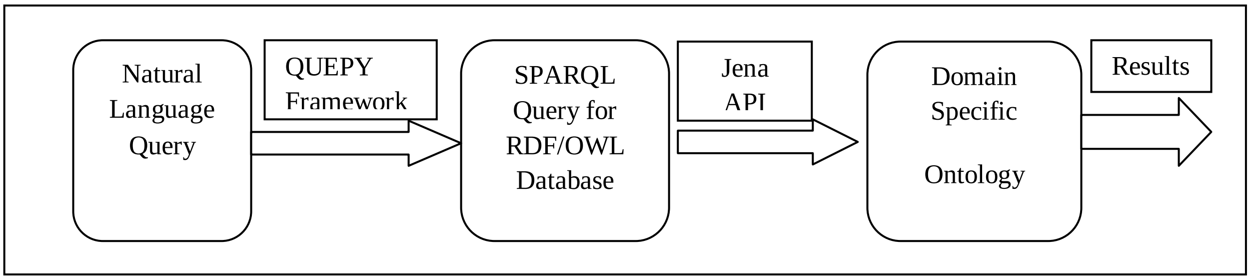

Figure 1: High level design of IRSCSD Architecture [1]

The core part of the design is domain specific Ontology building. Interface accepts queries in natural language which are converted into SPARQL query language through Python based QUEPY framework. Then the converted SPARQL queries are being fired to the Ontology through Apache's Jena API to fetch the results [1].

3. Prototype Ontology Developed for IRSCSD System

Ontology development is a complex and largely domain-oriented process that can be benefited from tool support. Finding an appropriate tool to develop ontology is the first step towards ontology development. Various tools for ontology development are compared based on certain features such as modeling features/limitations, base language, web support and use, import/export format, graph view, consistency checks, multi-user support etc [6]. The most dominant and domain-independent tool used is protégé as it supports many features like GUI , storage through JDBC etc. which are not supported by other many tools. It was found that Protégé tool is based on Java, is extensible, and provides a plug-and-play environment that makes it a flexible base for rapid prototyping and application development [7]. Protégé is a free and open- source ontology editor and framework for building intelligent systems [8]. Protégé is a tool which creates data into RDF data format. Moreover, it is popular as it has enough documentation on the web and is also extensible.

In an online survey [9] it was found, that the most dominant and domain-independent tool is protégé which is used by 75% respondent. One reason of such enormous number of developer tends toward protégé could be available online help by mailing list. So, Protégé Tool is used for the development of ontology in IRSCSD (Information retrieval system for computer science domain). We have used Protégé_3.4.8 tool to create ontology for computer science domain. Stack and Queue topic of data structure from computer science are chosen to create the prototype of system.

3.1 Methodology for Ontology Development

Various stages are there for developing ontology. First stage is to gather the detailed information of the domain. Second stage is to identify all the classes and subclasses for the ontology to be developed. Third stage is to set the properties between classes and subclasses. Properties are of two types: Object properties and data properties. Object properties usually describe relationships between two instances or two individuals of classes. Data properties describe relationships between instances and data values. Every property has domain and range. Fourth stage is to set the domain and range of every property. Comments can also be added to classes and properties for the domain explanation. Fifth stage is to create instances of classes and set their data and object properties to define relationships between the instances of various classes and subclasses Sixth stage is for consistency checking. Inbuilt reasoner can be used to check the consistency of ontology. Addition plug in like HermiT reasoner can also be used to check the consistency of the developed ontology. Sixth stage is to save the ontology in RDF/OWL format. Finally export the ontology in RDF or OWL data format to the required interface for execution of queries [1]. Finally, the prototype ontology developed for computer science domain has 371 RDF triples. Flow diagram for all the stages of ontology development is shown in figure 2 below.

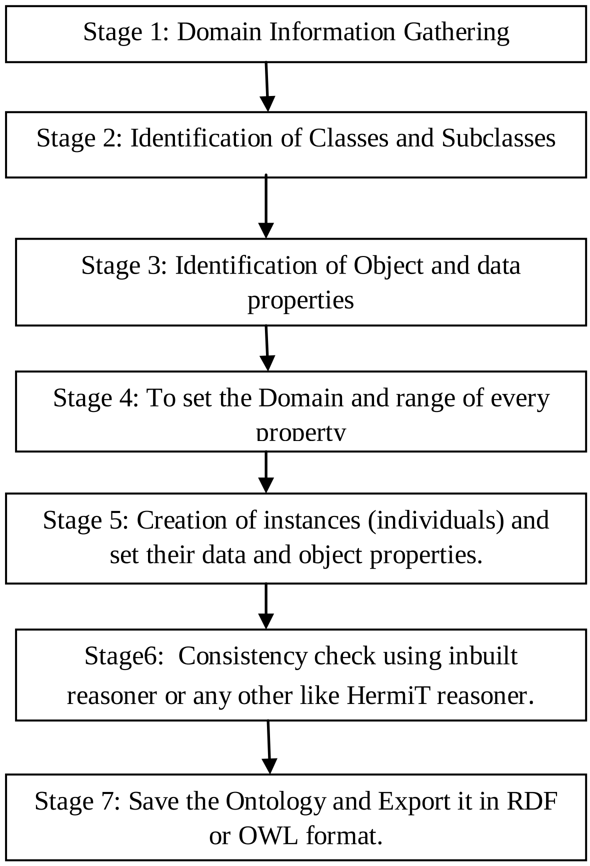

Figure 2: Steps for Ontology Building [1]

4. Ontology Evaluation Approaches and Metrics

Prototype ontology is developed for IRSCSD system considering two core topics (stacks and queues) of one of the subjects in computer science domain. In the emerging knowledge based society, performance and efficiency are very important which is based on evaluation. Ontology evaluation is the problem of assessing a given ontology from the point of view of particular criteria of application [4]. Evaluation is concerned with quality and correctness of the object being evaluated. So, ontology can also be evaluated on the above two aspects i.e. quality and correctness [10]. Building ontology correctly comes under verification (quality) of ontology and building the correct ontology comes under ontology validation (correctness) [10]. Framework/Methodology used for ontology evaluation can also be classified as validation framework or verification framework. The process of deciding on the quality of ontology in respect to particular criteria with a view of determining which in the collection of ontology would best suit a particular purpose. Ontology evaluation approaches fall into the four classifications which are application or task-based, user-based, gold-standard based and data driven evaluation. Application or task-based evaluation is based on using the ontology in an application and evaluating the results whereas user-based evaluation is done by humans who try to assess how well the ontology meets a set of predefined criteria, standards, requirements etc. In data driven evaluation, comparisons with a source of data about the domain to be covered by the ontology are done [4]. Lastly, the oldest approach is gold standard based evaluation which is based on comparing the ontology to golden standard which itself is ontology.

4.1 Layered Approach for Ontology evaluation

Ontology is considered to be a complex structure and it may be better to evaluate each level of the ontology separately than targeting the ontology as a whole [4]. First layer focuses on lexical, vocabulary, concept and data. Focus of this layer is on which concepts, instances, facts etc have been included in the ontology and the vocabulary used to represent or identify these concepts. Evaluation involves comparisons with various sources of data concerning the problem domain as well as techniques such as string similarity measures e.g. edit distance. Second layer is based on hierarchy or taxonomy. An ontology typically includes a hierarchical is-a relation between concepts. This is-a relation is the focus of specific evaluation efforts. Third layer covers all other semantic relations as ontology may contain other relations besides is-a, these relations may be evaluated separately. This includes measures such as precision and recall. Next layer is at context and application level which act as a fourth layer. In this, evaluation looks at how the results of the application where the ontology is to be used are affected by the use of the ontology. Fifth layer is for manually constructed ontology. Ontology must match the syntactic requirements of that language and this layer is known as syntactic level .Last layer is for structure, architecture and design. This is also for manually constructed ontology. To check whether the ontology meets the certain pre-defined design principles or criteria and its suitability for further development [4].

4.2 Ontology Evaluation Approaches at Various Layers of Ontology

Grouping of the ontology evaluation approaches can be done on the basis of the level of evaluation. Table 1 given below shows the relation between the various approaches for ontology evaluation and ontology layers. The first definition of ontology evaluation i.e. verification and validation can be found to span the different categories. Within task-based evaluation, methods and frameworks can be categorized towards either verification (quality) or validation (correctness).

4.3 Metrics for Ontology Evaluation

Separate metrics is needed for evaluation of quality and correctness of ontology. Always, there is one question in mind that whether software evaluation metrics are applicable to ontology evaluation or not. We should distinguish ontology from software process and rather seeing them as data models. Correctness Metrics for

Ontology Evaluation (Validation) should be relevant to information retrieval. Metrics like precision, recall or coverage can be used. This comes under data-driven ontology evaluation. Ontology evaluation should reflect the degree of approximation as shown in figure 3 below.

Table 1: Ontology evaluation approaches at various layers of ontology [4]

Level	Golden Standard	Application-Based	Data Driven	Assessment By Humans
Lexical,vocabulary,concept,data	Yes	Yes	Yes	Yes
Hierarchy , taxonomy	Yes	Yes	Yes	Yes
Other Semantic Relations	Yes	Yes	Yes	Yes
Context ,Application	No	Yes	No	Yes
Syntactic	Yes	No	No	Yes
Structure , Architecture , Design	No	No	No	Yes

So, the methodology or framework for ontology evaluation can come under three categories as discussed in above sections. Below given table 2 show all the approaches.

Table 2: Approaches for Ontology Evaluation

Quality/Correctness based	Level/Layer based	Classifications
Verification Framework	Lexical, vocabulary, concept ,data	Comparison against a gold standard
Validation Framework	Hierarchy , taxonomy	Application or task- based evaluation
	Other semantic relations	User-based evaluation
	Context, application	data-driven evaluation
	Syntactic	
	Structure, architecture, design	

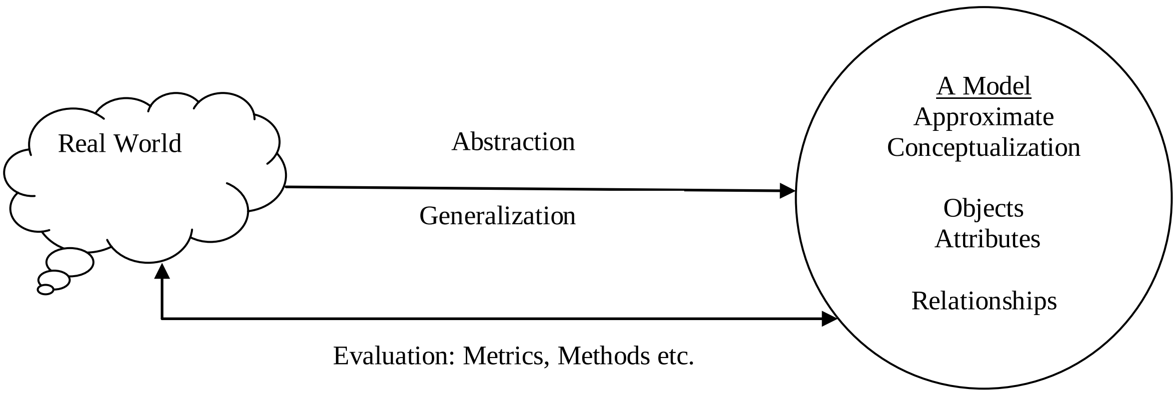

Figure 3: Relationship between ontology and real world [10]

Quality metrics for ontology evaluation is based on measurement tradition in software engineering [10]. Measures of a program's internal attributes (such as coupling and cohesion) are believed to influence external quality attributes (such as maintainability and performance). Coupling is degree of interdependency and cohesion measures the strength of relationship between modules etc. related metric suite consists of four metrics where the metrics are: syntactic quality, semantic quality, pragmatic quality and social quality [10].

Broadly, syntactic and semantic aspects can be categorized under structural metrics. Functional metrics focuses on the intended use of the ontology and its components. Lastly, usability-profiling focuses on the communication aspect of an ontology i.e. concerned with pragmatic quality and social quality. Pragmatic quality is related to usefulness and usability of the system [10].

4.4 HermiT OWL Reasoner

HermiT is reasoner for ontologies written using the Web Ontology Language (OWL). Given an OWL file, HermiT can determine whether or not the ontology is consistent, identify subsumption relationships between classes, and much more. In our tool, we are using protégé 4.3 and it comes with HermiT 1.3.8 pre-installed. HermiT is under the GNU Lesser General Public License (LGPL). HermiT is the first publicly-available OWL reasoner based on a novel "hypertableau" calculus which provides much more efficient reasoning than any previously-known algorithm. Ontologies which previously required minutes or hours to classify can often by classified in seconds by HermiT, and HermiT is the first reasoner able to classify a number of ontologies which had previously proven too complex for any available system to handle. HermiT uses direct semantics and passes all OWL 2 conformance tests for direct semantics reasoners [11].

5. Implementation of Task Based Approach for Ontology Evaluation

In an application specific ontology evaluation the quality of ontology is directly proportional to the performance of an application that uses it. This typically involves evaluating how effective ontology is in the context of an application. Application here may be an actual software program or a use-case scenario. Task-based ontology evaluation can be qualitative as well as quantitative. The qualitative type of evaluations basically relies on user or expert judgments, whereby it is left open whether ontology engineers, system users or domain experts ought to be the judges [12]. Qualitative Task based evaluation has been done by executing SPARQL queries of prototype ontology developed and fetching the desired results. Small prototype ontology was on the core topics of data structures subject of computer science domain. Core topics chosen are Stack and Queues. Qualitative Task based evaluation has been done by executing SPARQL queries of prototype ontology developed and fetching the desired results. SPARQL queries were developed for those 40 queries. Two SPARQL queries are shown below in table 3 each from stack and queue topic. In quantitative task based evaluation, the system will tag (means attach labels) concept pairs with appropriate relations and all the other components of the system will remain constant except for the ontology dependent parts. This allows for the effects of the ontology on the performance of the system to be quantified. There are two problematic issues for such evaluations. Firstly, the difficulty of assessing the quality of the supported task example searches. Secondly, creation of a clean experimental environment where no other factors but the ontology influences the performance of the application.

Table 3: Sample SPARQL queries for Stack and Queue

Domain Topic	SPARQL Query	Natural Language Query
Stack	PREFIX uni:<http://www.semanticweb.org/bansals/ontologies/2014/7/Stack.owl#> Select ?Operations where{ Uni:stack Uni:core_operations ?Operations}	What are the various operations on stack?
Queue	PREFIX uni:<http://www.semanticweb.org/bansals/ontologies/2014/7/Stack.owl#> Select ?operations where {uni:queue uni:removal_process ?operations}	Process of Removing an element from the queue is called as?

Two approaches were used for executing these SPARQL queries on ontology. The first approach is to run SPARQL query through protégé and its interface for executing query along with the fetched result is shown in figure 4 below. The outcome of first SPARQL query on stack should be peek, pop, new and push operations. In, second approach SPARQL query is executed through Apache's Jena Fuseki server which is GUI based whose interface is shown in below figure 5.

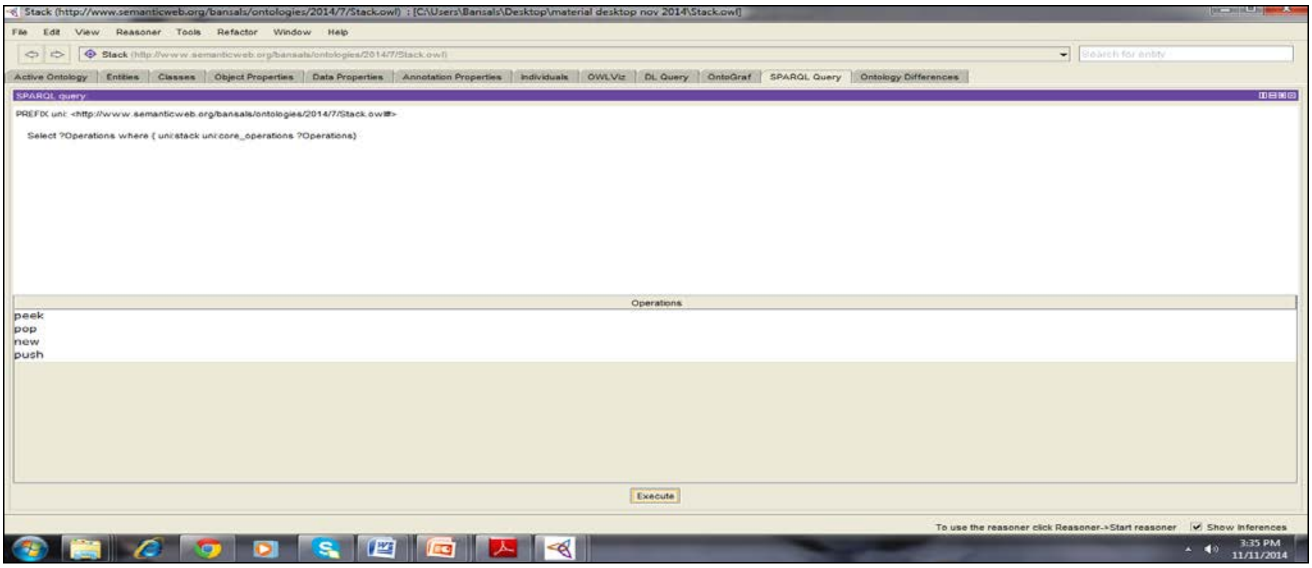

Figure 4: Running SPARQL query through protégé [4]

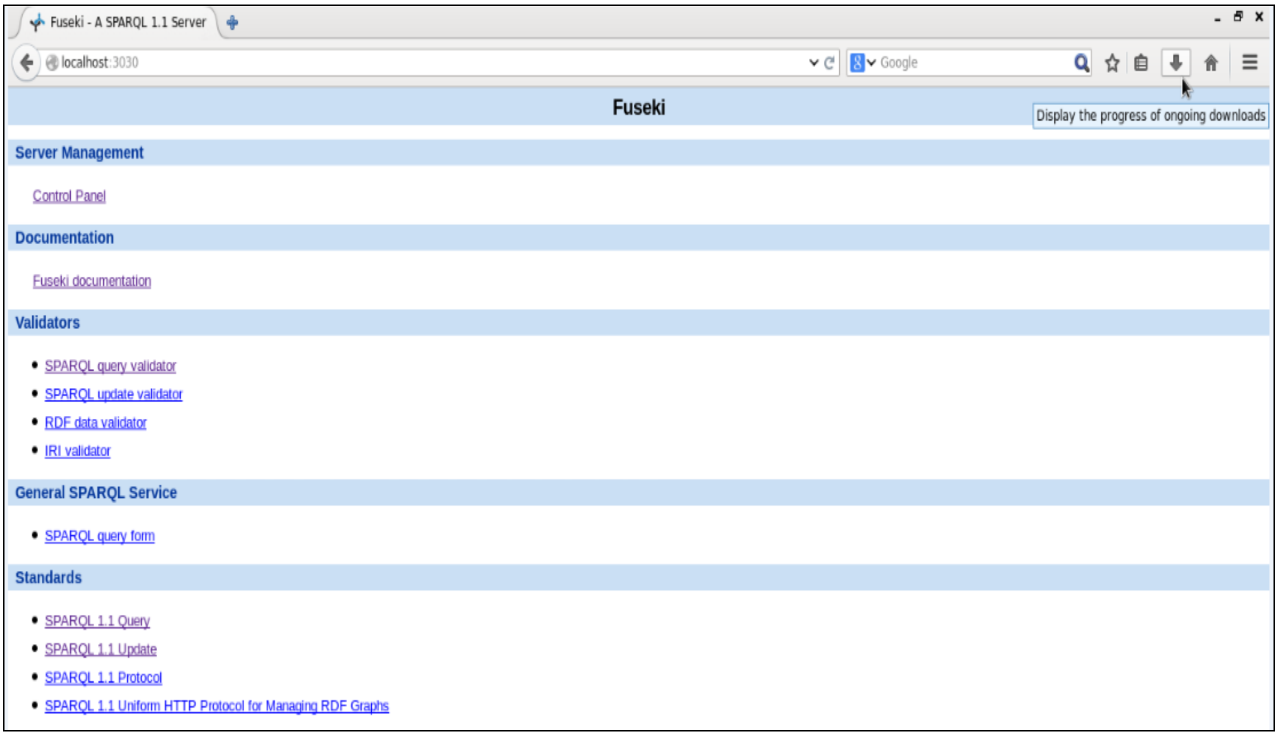

Figure 5: Interface of Jena Fuseki Server [4]

6. User-Based Evaluation

Evaluation of ontology through users experiences i.e. capturing the subjective information about the ontology and not assessing semantic validity and consistency of the ontology. Subjective information is one person's opinion. It captures two types of information. First is source-metadata from the viewpoint of the ontology authors. Second is third-party metadata from the viewpoint of the users of the ontology [10]. It is difficult to establish objective standards for the criteria (metrics) for evaluation. Also, it is also hard to establish who the right users are.

7. Data Driven Ontology Evaluation

This evaluation gives answer to the question how well a given ontology fit the domain knowledge? It is done by comparing the ontology with the existing data sources available like textual documents about the domain [4]. Focus is on how appropriate ontology covers a topic of the corpus through the measurement of the notions of precision and recall i.e. correct model of domain is created or not. Precision metric is the total number of correctly found knowledge over whole knowledge defined in ontology. Recall metric is the total correctly found knowledge over all knowledge that should be found. The amount of overlap between the domain specific terms and the terms appearing in the ontology is used to measure the fit between the ontology and the corpus [4]. For ontology on factual information, evaluation examines whether facts mentioned in documents can be derived from ontology or not. The major limitation of data driven ontology evaluation is that domain knowledge is implicitly considered to be constant. This is inconsistent with reality and with literature's assertions about the nature of domain knowledge.

8. Gold Standard Based Evaluation

In Gold Standard based ontology evaluation the quality of the ontology is expressed by its similarity to a manually built Gold Standard ontology. This typically compares ontology against a "gold-standard" which is suitably designed for the domain of discourse [10]. Gold standard is an ontology considered to be well constructed to serve as reference. Measuring the similarity between ontology (the target and gold-standard) i.e. one can compare ontology at two different levels: lexical and conceptual. Lexical comparison assesses the similarity between the lexicons (set of labels denoting concepts) of the two ontology. At the conceptual level the taxonomic structure and the relations in the ontology are compared. Comparisons can be done on the arrangement of the class instances and the hierarchical arrangement of the classes. Gold-Standard does offer an avenue to evaluate ontology. Major limitation is that the gold standard itself needs to be evaluated. Thus far, it is difficult to establish the quality of gold standard and hence, in the case of discrepancies in the results, it will be difficult to determine the source of error. It will be difficult to tell if the gold standard itself is incorrect or the results are in fact flawed [4].

9. Conclusion

Ontology evaluation is an important open problem and there is no single best approach to evaluate the ontology. The Choice of suitable approach for ontology evaluation must depend on the purpose of evaluation, the application in which the ontology is to be used and on what aspect of the ontology we are trying to evaluate. Purpose of evaluation and application context is an important factor which helps in decision for ontology evaluation approach to be followed. Also, comparing different ontology is only possible if they can all be plugged into the same application. This paper has integrated the concepts namely, ontology development process, ontology evaluation approaches and layers at which ontology evaluation should be done. This integrated framework will help knowledge engineers to build accurate ontology that serve best for desired applications. The increase in the use of ontology has heightened the need for evaluating the ontology. So, ontology evaluation is an important task which is to be done for the wide adoption of semantic web and other semantic-aware applications.

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