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A Synthesis Survey of Ontology Evaluation Tools, Applications and Methods to Propose a Novel Branch in Evaluating the Structure of Ontologies: Graph-Independent Approach

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Abstract

Diverse tools, application and methods can logically be organized in clear categories (i.e., Gold standard, Application, Data-driven and Human assessment) or their dimensions (i.e., Functionality (task-based), Usability based and Structural evaluation). This paper attempts to propose a novel branch in structural analysis of ontology through analyzing current methods. Structural dimensions can be involved in evaluating ontologies when the research attempts to analyze the graph representation based on Conceptual Graph (CG). Two types of nodes (i.e., concepts and conceptual relations) can be merely linked with one another via logical conjunction. When logical conjunction between concepts and conceptual relations were removed, the remaining components would be independent domains which would no longer bear the meaning of graph. The separate concepts and conceptual relations cannot be involved in the notion of the graph-dependent approach. Thus, there is the lack of a novel branch in structural analysis which is called Graph-independent approach.

Keywords: Ontology Evaluation Method; Ontology Evaluation Tools and Applications; Categorization and Classification; Structural Analysis; structural ontology evaluation; Conceptual Graph (CG); Graph Representation; Graph-dependent Approach; Graph-Independent Approach.

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1. Introduction

Ontology quality is an important area in ontology verification and validation for improving ontologies via the systematic analysis. Ontology evaluation relates to maintenance for reducing failures by comparing between different ontologies to select the best one [1]. In this matter, diverse tools, application [2] and methods as well as several approaches have been proposed [3] for evaluating ontologies [4] to categorize these tools, application and methods. These methods should logically be organized in clear categories based on specific approaches to clarify their features and applications in evaluating ontologies. This article attempts to organize influential ontology evaluation tools, application and methods in identifying their characteristics to clarify research gap. In the case, this article focuses on three main purposes: Firstly, determining the related approach (s) in categorizing ontology evaluation methods, secondly, synthesizing the characteristics as well as similarities and differences between ontology evaluation tools, applications and methods base on proposed approaches and finally, identifying limitation of the methods and research gap in proposing new methods. There are various classification schemes in categorizing evaluation method. However, verification and validation aspects are the common points between various classification schemes in categorizing ontology evaluation methods [5].

This paper endeavors to classify tools, applications and methods which are closely related to ontology evaluation based on some approaches. There are various approaches in categorizing ontology evaluation methods. In this article, the approaches of classifying can be divided into two main groups. The First group is ontology evaluation categories which are Gold standard, Application, Data-driven and Criteria-based evaluation by Human assessment. The second group is ontology evaluation dimensions which comprises of Functionality (task-based), Usability based and Structural evaluation. According to these approaches, the related tools, applications and methods in ontology evaluation can be categorized into the mentioned two main groups. In this article, we attempt to categorize and identify the characteristics of some of the influential tools, applications and methods in ontology evaluation. Ontology tools and applications comprise of ODEval, OntoManager, S-OntoEval, WebCore, OntoEdit, Ontology Selection, On-To-Knowledge and Linguistic base approach. Moreover, ontology evaluation methods are Natural Language Application Metrics, EvaLexon, OntoCase, OntoClean and OntoMetric. Hence, the mentioned tools, applications and methods are explained to clarify their features and applications. Furthermore, they can be involved with one or more dimensions and can be classified via related categories.

This paper attempts to propose a novel branch in structural analysis of ontology through analyzing the current methods and explaining the principles of structural analysis in ontologies. This main purpose can be divided in to the following objectives:

- To clarify a whole picture about the characteristics of the tools, applications and methods in ontology evaluation.

- To classify the tools, applications and methods in analyzing their specific features.

- To prepare a capability in comparing the tools, applications and methods with one another.

• To explain the current approach in structural analysis of ontologies.

• To identify a research gap in proposing a novel branch in structural analysis of ontologies.

2. Approaches and dimensions in categorizing ontology evaluation methods

The question of ontology evaluation is one of the major issues in the field of ontology engineering and for that reason diverse group of scientists proposed a variety of methods for ontology evaluation [3]. Researchers believe that various viewpoints in ontology engineering, different kinds of ontologies and distinct approaches on issues in ontology evaluation are the main causes of development of different kinds of methods for ontology evaluation [6]. Core literatures in ontology evaluation reveal that more than a dozen methods are proposed by this time and the problem of selecting the suitable one for a specific reason have become more complicated [4; 7]. In this case, several approaches (i.e., categories) [8] or dimensions for evaluating ontologies have been proposed in verifying and validating ontologies. Ontology evaluation methods can be classified via their related approaches [6] or based on the dimensions [9; 10]. Moreover, there are several researches to organize these categories or dimensions basis into a logical classification or appropriate arrangements. Therefore, ontology evaluators proposed distinct approaches or criteria to evaluate ontologies while some of the researches struggled to organize these methods.

In identification of ontology evaluations methods, two paradigms have been taken into account, ontology verification and validation [11]. Ontology verification deals with building the ontology correctly [12] or ensures that ontology has been designed correctly and it also examines the encoding of the specification [13]. Ontology validation refers to the correspondence between the semantics of the model and the real world for which the ontology was designed [12]. In other words, validation ensures that the correct ontology has been designed and it refers to whether the meaning of the definitions meets with the conceptualization [13]. Literature reviews found that there were several proposals for ontology evaluation basis of ontology verification and validation [7; 8]. These proposals consist of various categories and dimensions in evaluating ontologies [8] depending on what kinds of ontologies are evaluated and for what purpose [14]. The ontology evaluation approaches can be classified into four categories as follow: gold standard, application based-ontology assessment, comparison with a source of data and human assessment [12] as described in [8]. Furthermore, there are three dimensions in evaluating ontologies, structural, functional and usability analysis [10; 9]. The mentioned categories and dimensions are our source in synthesizing process in classifying ontology evaluation methods, approaches and tools.

2.1. Ontology evaluation approaches

Various approaches have been considered in evaluating ontologies in the literature with regard to the kind of ontology or its purpose [14]. Most approaches in ontology evaluation can classify into one of the following categories: [6]

a) Gold standard: This category covers approaches in evaluating ontologies to test ontology quality with regard to similarity to a manually built Gold Standard ontology [15; 16; 17] which may itself be an ontology [18]. In general, comparing one ontology with another is the basic element for this idea [19] through using similarity measure or a distance function between ontologies [8; 20] to allow easy evaluation of several levels of the ontology specifications (e.g. lexical, taxonomic, relational). In this kind of evaluation assumes that the gold standard represents well and captures all the significant knowledge of the domain [21].

b) Application: This category classifies the ontology evaluation approaches based on application [22], task and use cases of ontology. Thus, application is a kind of the task-based approach to evaluate the ontology applications [23; 7]. The related approaches, in fact, operate based on using the ontology in an application and evaluating the results (e.g. [24]).

c) Data-driven: This category can be seen as a function of the ontology and the domain-specific data corpus [8; 25]. It means that data-driven focuses on comparing between ontology and corpus [26] (e.g. a collection of documents or data) [7] about the domain or corpus to be covered by the ontology [27].

d) Criteria-based evaluation by Human assessment: The evaluation approaches according to criteria [26] where evaluation is done by human to assess that the targeted ontology [28] meets a set of predefined criteria, standards, requirements, etc. (e.g. [29]).

2.2. Ontology evaluation dimensions

Ontology evaluation consists of two main aspects in validating and verifying ontologies. These aspects can measure three major issues [9], structural, functional and usability-profiling issues [10]. Ontology evaluation focuses on one or more of the following dimensions:

a) Functionality (task-based): This dimension measures how well an ontology serves its purpose as part of a larger application [30]. For example, the measures in functional analysis are related to the intended use [31; 2] of an ontology and of its components (i.e., their function) [10].

b) Usability based: This dimension assesses the pragmatic aspects of the ontology, i.e., metadata and annotation [32]. For instance, the related measures of usability-based dimension focus on and depend on the level of annotation (i.e., indexing and organizing) of the considered ontology [10] and its pragmatics [2].

c) Structural evaluation: This dimension measures the properties of the ontology viewed as a formal graph basis on graph theory. This kind of evaluation identifies structural properties in ontology viewed as a graph. In this matter, structural measures are used in graph representations to identify that two nodes in a graph are related [9] in which these consist of discussions on the set of graph nodes such as root, leaf, sibling, etc. [4; 33] in various kinds of ontological relations.

3. Ontology evaluation tools, applications and methods

There are tools, applications and methods to rank, compare, verify and validate similar ontologies [19] that are either manual or automatic [34] in checking ontology quality, inconsistency and fulfillment to ontology requirements. The manual or automatic implementations of ontology development and evaluation increase the complexity and unsolved problems in the ontology evaluation area [35; 36]. Therefore, to achieve a reliable ontology, complementary ontology evaluation methods and tools are appreciated [2]. Subsequently, Ontology evaluation consists of some tools, applications and methods to investigate on various issues in solving problem to increase the ontology quality in the form of manual and automatic implementations.

In this article, the considered ontology evaluation methods, tools and applications are the most well known and most used method [37] in the field of ontology evaluations. Furthermore, the considered methods in this research are influential ontology evaluation methods, especially OntoClean and OntoMetric [38]. In this section, firstly, the applications, tools and methods are explained in the field of ontology evaluation. Secondly, synthesizes of the classification of the considered tools, applications and methods are demonstrated based on the related categories and dimensions in ontology evaluation and finally, the main purpose in synthesizing ontology evaluation methods, tools and applications is analyzed which is the usage of structural analysis in ontology evaluation .

3.1. Synthesis of the considered methods, applications and tools

Various numbers of tools, applications and methods have been proposed and developed to evaluate ontologies by relying on different perspectives [2]. In this section, the characteristics of the methods, tools and applications are synthesized to draw a clear picture of their roles and position in developing and evaluating ontologies. These roles and positions clarify through explaining the goals, descriptions and specifications [39] of methods, tools and applications in the field of ontology evaluation. These summarized explanations consist of a capacity to enhance the understanding about each methods, tools and applications as well as prepare a foundation to compare the considered methods, tools and applications with one another. The following table shows the synthesis of the related information about each tool, application and method in ontology evaluation.

Table 1: Synthesis of the characteristics of the considered tools, applications and methods

Tools & applications	Goal	Description	Specification
Tools			
ODEval	Evaluate ontologies regarding knowledge representation.	This *tool* Evaluates the concept taxonomy of the ontologies to detect inconsistencies and redundancies in taxonomies and performs syntactic evaluation of RDF(S), DAML+OIL, and OWL ontologies.	- Implements in the ontology languages like OWL - Tackles circularity, partition and redundancy problems in taxonomy. Focus on knowledge representation.
OntoManager	Evaluate the truthfulness of ontology regarding its problem domain.	This *tool* Finds the weak points and modifies them in the ontology regarding the end-users' needs/requirement and focuses on the analysis of usage data via relying on users' interactions.	- Follows a statistical approach to recognize the relevance of concepts - Optimizes ontologies with

Tools & applications	Goal	Description	Specification
			respect to the users' needs. - Rely on ontologies' structure to expand the knowledge base. - Covers the cleaning and validation of the data for achieving the required quality
S-OntoEval	Evaluates ontology quality via various metrics	This *tool* evaluates and improves ontologies through a metric-based measurements regards to syntactic, semantic, and pragmatic viewpoints and analyzing cognitive aspects in ontology semantics.	- Evaluates ontology quality regard to particular task - Metric-based evaluation. - Focuses on meta data regard to ontology's usefulness.
WebCore	Increase of the performance of the ontology retrieval and recommendation.	This *tool* operates for ontology reuse and evaluation in the form of automatic operation to match with users' opinion and experiments.	- Established for Collaborative ontology reuse and evaluation. - Adapts to Web applications. - Problem description by operating similarity measures.
OntoEdit	Evaluate ontology based on a methodology that results in the inference capabilities.	This *tool* has capacity to evaluate ontologies regard to required specifications and formal evaluation in the form of automatic operation.	- Tests consistency in ontological relationships - Rely on philosophical notions to clean taxonomies (i.e. OntoClean) - Allows creating, browsing, maintaining and managing ontologies. - OntoStudio is the related ontology editor tool.
Ontology Selection	Checks ontologies regard to various groups of criterion whether the targeted ontology satisfies the criteria.	This automatic *tool* covers various perspectives in ontology evaluation to select an ontology.	- Analyses the best coverage of an ontology for a given corpus. - Considers the real semantic web - Rely on popularity or knowledge richness. - Focus on selecting ontology with respect to information needs.
Applications			
On-To-Knowledge	Develops ontologies for knowledge management application	This *application* method has capacity to test ontologies with regard to the competency	- Includes a cycling back process to improve the proper

Tools & applications	Goal	Description	Specification
		questions identified in the specification document as well as user feedback.	level of users' satisfaction. - Tests the ontology usefulness in the application.
Linguistic base approach	Evaluate ontologies rely on vocabulary, taxonomy and (non-taxonomic) semantic relations	This *application* follows the task-based or application approach and also gold standard in ontology evaluation	- Analysis vocabulary and ontological relations. - Build an appropriate benchmark to examine a given ontology
Methods			
Natural Language Application Metrics	Evaluate the content of ontologies regarding various metrics.	This method result in capturing the ontology population or concepts with instances drawn from textual data based on automatic operation. Ontology population is formed when instances are added to the concepts.	- Uses natural language applications - Captures the ontology population - Focuses on the users' needs - Compare two ontologies - A metric-based evaluation
EvaLexon	Develops evaluation procedure for ontology miners from text.	This method operates on the results of automatic ontology mining techniques where ontologies are created from text documents in the application domain	- Applies at the linguistic level of words - Uses some of the criteria & related metrics
OntoCase	Evaluate ontology quality through implementing semi-automatic patterns base on Ontology Web Language (OWL)	This method focuses on the retrieve, reuse, revise and retain phases in implementing for Ontology Web Language (OWL)	- Pattern ranking to evaluate ontology quality - Enhances of ontology integration - Structures the exit knowledge - Improves ontological relations
OntoClean	Evaluate formal ontology in assessing upper-level ontologies to detect both formal and semantic inconsistencies.	This method prepares a logical foundation to clean ontologies in terms of taxonomic relations overloading regarding correctness criterion especially for the upper levels ontologies based on philosophical notions.	- Bases on philosophical notions - Discusses on formal ontology - Focuses on taxonomic relations - OntoEdit tool supports the method. - Comparing to Gold Standard to detect inconsistencies.
OntoMetric	Compare and choose the appropriate ontology for a new project	This is a quantitative method via operating automatic and semi-automatic applications to check ontology quality, Inconsistency and fulfill of ontology requirements for comparing and selecting ontologies.	- Focuses on metric approach. - Presents a taxonomy of characteristics for evaluating ontologies - Focuses on lexical, vocabulary, concept

Tools & applications	Goal	Description	Specification
			and data level - Compares ontologies to identify the best one. - Determines evaluation using goals/objectives.

Table 1 shows the characteristics of the considered tools, applications and methods in evaluating ontologies. In this case, six tools, two applications and five methods are taken under consideration to clarify their roles and position in the field of ontology evaluation. At first glance, the considered tools and majority of methods support via an automatic operation in developing and evaluating ontologies. In comparison of the goals and descriptions of the considered tools, applications and methods, there is no strong similarity between their goals, descriptions and specifications. It means that the considered tools and methods have focused on a specific area or topic in terms of the level and area in ontology evaluation. However, the improvement of the ontology quality is the main purpose of the considered tools, applications and methods to develop and evaluate ontologies. Consequently, the mentioned tools, applications and methods rely on techniques and performance to focus on the specific area in evaluating ontologies instead of assessing the ontology as a whole. In this manner, the mentioned applications and tools have not prepared a general view point in verifying and validating ontologies. Hence, there is a gap in proposing a comprehensive ontology evaluation method to represent the whole picture in evaluating ontologies.

3.2. Synthesis of the classification of the considered tools, applications and methods

The tools, applications and methods should logically be organized in clear categories to clarify their features in evaluating ontologies. There are various classification in categorizing ontology evaluation methodology, methods and tools. In this manner, there are various viewpoints in classifying ontology evaluation methods. However, verification methods to confirm the ontology is constructed suitably and validation methods to certify the ontology to express the real world are the common points between various classification schemes in categorizing ontology evaluation methods [5].

In this section, the synthesis of the classification of considered tools, applications and methods presents based on their approach in ontology evaluation. As stated previously, ontology evaluation scientists proposed two main aspects in classifying ontology evaluation approaches. These main aspects are *categories* and *dimensions* in classifying ontology evaluation approaches. Most approaches in ontology evaluation can classify based on *categories* which are the Gold standard, Application, Data-driven and Criteria-based evaluation by Human assessment [6]. Moreover, there are three *dimensions* in classifying approaches in ontology evaluation method, applications and tools which are the dimension of the Functionality, Usability-based and Structural evaluation. Therefore, the considered tools, applications and methods are classified based on two mentioned aspects in the following sections.

The following table presented the classification of the considered tools and applications in identifying their approach in ontology evaluation based on the related categories and dimensions.

Table 2: Synthesis of the classification of the considered tools and applications based on the related categories and dimensions

Categories & Dimensions / Tools & applications	**Categories**				**Dimensions**		
	Gold standard	Application	Data-driven	Criteria-based by Human assessment	Functionality	Usability-based	Structural evaluation
ODEval		√		√			√
OntoManager		√		√	√	√	
S-OntoEval		√		√	√	√	√
WebCore	√	√		√		√	
OntoEdit		√		√			√
On-To-Knowledge		√	√			√	
Ontology Selection			√	√	√	√	
Linguistic base approach	√	√			√		√

Table 2 demonstrates a classification of considered application and tools in terms of their approach based on categories and dimensions in classifying ontology evaluation applications and tools. At first glance, each application and tool comprises of at least three kinds of approach with regard to categories and dimensions. S-OntoEval covers the most approaches (i.e, five from seven approaches) with respect to the related category or dimension. Almost all of the applications and tools (i.e., seven from eight) have relied on "Application-based" and "Criteria-based" evaluation approaches in the categorization aspects. On the other hand, ontology evaluation applications and tools, generally, have focused on "Usability-based" evaluation in the field of dimensional aspect in ontology evaluation classification. Only four applications and tools which are ODEval, S-OntoEval, OntoEdit and Linguistic base approach have relied on "Structural evaluation" approach. Accordingly, the majority of the considered applications and tools have focused on "Application-based", "Criteria-based" and "Usability-based" approaches in ontology evaluation. S-OntoEval is the only ontology evaluation tool which covers the majority of the approaches in ontology evaluation. Consequently, the related method of the mentioned applications and tools focus on the minority of the approaches in ontology evaluation. In this case, the mentioned applications and tools have not covered almost all of the approaches in evaluating ontologies.

The considered methods are categorized based on their approaches in ontology evaluation based on the related categories and dimensions in this section.

Table 3: Synthesis of the classification of the considered methods based on the related categories and dimensions

Categories & Dimensions / **Methods**	**Categories**				**Dimensions**		
	Gold standard	Application	Data-driven	Criteria-based by Human assessment	Functionality	Usability-based	Structural evaluation
Natural Language Application Metrics		√	√		√	√	
EvaLexon		√	√	√	√		
OntoCase			√				√
OntoClean	√	√		√	√		√
OntoMetric		√		√	√	√	√

Table 3 clarifies the position of considered ontology evaluation method based on their related dimension and categorization. The "Application-based" and "Functionality" evaluations are the most popular approaches in ontology evaluation methods respectively in categorization and dimensional aspects. Moreover, EvaLexon and OntoClean methods cover the majority of the approaches in categorization aspects. On the other hand, OntoMetric focuses on all of the approaches which are Functionality, Usability-based and Structural evaluation in dimensional aspects in classifying ontology evaluation methods. OntoCase relies on only one approach in the categorization and dimensional aspects, respectively “Data-driven” and “Structural evaluation” approaches. In contrast, OntoClean and OntoMetric have covered the majority of the approaches (i.e., five from seven approaches) in ontology evaluation. Subsequently, the majority of the ontology evaluation methods have focus on the “Application-based” and “Functionality” in the field of ontology evaluation. Furthermore, the majority of the ontology evaluation approaches have practically taken under consideration by OntoClean and OntoMetric. In this matter, OntoClean and OntoMetric can be taken into account as the comprehensive methodologies in ontology evaluation in order to cover the majority of the approaches in ontology evaluation. Specifically, OntoClean and OntoMetric have focused on structural analysis which is the dimension that this paper intends to focus on in evaluating the structure of ontologies.

3.3. The main purpose in synthesizing ontology evaluation methods, tools and applications

Ontology evaluation methods, tools and applications cover various fields or levels in evaluating ontologies basis of their approach and dimensions. On the other side, there is ontology evaluation method that focused on one dimension and one approach such as OntoCase (Table 3). However, Ontology evaluation methods usually rely on the usage of multiple dimensions for the sake of their evaluation purposes or compare the results of evaluation based on various dimensions and categories [13]. For instance, OntoMetric (Table 3) focuses on functionality, usability-based and structural evaluation as ontology evaluation dimensions while this method covers some categories such as application based-ontology assessment and criteria-based by human assessment [37]. On the other hand, EvaLexon (Table 3) more focuses on functional dimension while it relies on application based-ontology assessment, Data-driven and criteria-based by human [40; 37] as categories and approaches in ontology evaluation. However, structural analysis as a dimension is generally related to criteria-based evaluation as a category, but this dimension can involve in analyzing application assessment (i.e., a category) of ontologies [13]. Consequently, different kind of ontology evaluation methods, tools and applications might have been covered various dimensions or categories for the sake of ontology evaluation based on their purposes basis of the level of evaluation.

This article attempts to show the identification of the ontology evaluation methods, tools and applications through analyzing their characteristics basis of their approach and dimension in ontology evaluation. Moreover, the synthesis of classification of the ontology evaluation methods, tools and applications helps us to clarify their related approaches and dimensions. In this matter, table 2 and 3 shows the situation of the ontology evaluation methods, tools and applications regarding their related dimensions, especially structural analysis. This situation prepares a basis for recognizing the priorities of the ontology evaluation methods, tools and applications in selecting their specific dimension. In other words, the situation shows the level or field of assessment in ontology evaluation or demonstrates the dominant domain in ontology evaluation regarding various dimensions, especially structural analysis which is the source for determining the research gap in proposing a naval method in ontology evaluation. Therefore, in the following section, we attempt to focus on the research results (Table 2 and 3) which are derived from the synthesis of the classification of the considered tools, applications and methods to determine the situation regarding the usage of structural analysis in ontology evaluation, main purpose of this section, in proposing a new method in structural analysis.

4. Structural dimensions in ontology evaluation

The results of table 2 demonstrates that majority of the applications and tools in the categorization aspects have relied on “Application-based” and “Criteria-based” evaluation approaches and focused on “Usability-based” approach in the dimensional aspect. Moreover, the “Application-based” and “Functionality” evaluations are the most popular approaches in ontology evaluation methods in categorization and dimensional aspects respectively. In contrast, OntoClean and OntoMetric have covered the majority of the approaches in ontology evaluation. Therefore, the considered applications, tools and methods did not possess all of the approaches mentioned here in evaluating ontologies, especially structural analysis in evaluating the structure of ontologies which is the dimension that this paper intends to focus on. In spite of, the importance of the structural analysis in analyzing ontology logical structure [4] which is the main focus of this article in proposing the ontology evaluation method, structural analysis was taken into account by no more than half of the applications, tools and methods.

Ontology evaluation consists of two main aspects, validation and verification of ontologies. These aspects can measure three major issues, which include [9] structural measures, functional measures and usability-profiling. Despite, the importance of structural analysis in ontology structure, the majority of literatures on ontology evaluation have focused on functionality issues, rather than structural ones [10]. Therefore, main focus of the investigations has been on the functional [4] and usability dimensions. Thus, in order to maintain a balance between the investigations done on other issues, structural analysis should also be taken into consideration as a dimension in evaluating ontologies.

Structural analysis has specific capacities which enable this dimension to have major effects on evaluating the structure of ontologies. To begin, an ontology is a fairly complex graph structure composed of concepts and relations [41] which are evaluated in structural analysis. In other words, the structural dimension fulfills the evaluation of concepts and relations in ontology logical structure [41; 42] where entities are represented as nodes [33]. Basically, the structure-based evaluation is suitable in prevention of errors propagating to other evaluation levels in the elements of ontology graph structure [43]. Moreover, structural analyses and their related measures can be used to automatically operate in evaluating the structure of ontologies [44]. Hence, structural analysis proves to be an important dimension in the field of ontology evaluation.

The structural dimension can be classified into two major groups of approaches as explained below:

4.1. Graph-dependent approach in structural analysis

When the research attempts to analyze a graph representation in structural ontology evaluation, structural dimensions and related measures must be used [10]. In other words, an ontology’s structural dimension is represented by its graph structure [43] or ontology-graph structure [45; 46] or graph-based ontology representation [47]. In this matter, structural analysis and related measures are used for evaluating graph representations that are based on Conceptual Graph (CG) [48] or Conceptual Graph Theory [49] to identify the relation of two nodes in a graph [9] or the relation of two types of nodes, subject and object nodes [50] similar to relations between concepts [41] underlying a graph structure [51; 52]. In this sense, structural dimension only focuses on structural analysis which is closely related to the graph-representation, graph structure and a set of graph nodes based on Conceptual Graph (CG) in evaluating the structure of ontologies.

A conceptual graph (CG), in fact, is an ontology-graph structure [45] or a graph representation that provides a logic base on the semantic networks [48] as a basis for the evaluation of the structure of ontologies [10]. Ontology-graph structure plays a role in demonstrating a knowledge representation scheme [49] which is derived from a creative work on the existential graphs, proposed by Peirce [53; 54; 55]. This idea has been further developed by Sowa [56; 57]. The [48] developed a version of Conceptual graphs as an intermediate language for mapping natural language questions and assertions to a relational database [48]. Conceptual graphs can be thought of as a formalization and extension of semantic networks. In this matter, graphs are labeled with two types of nodes (i.e., concepts) which represent objects, entities or ideas and relation nodes which represent relations between the concepts in the structure of semantic network [49]. Willems [58], Chein and Mugnier [59] and Corbett [60; 61] have formalized the Sowa's original idea in analyzing the structure of ontologies [49].

The developed version of conceptual graph which was proposed by Sowa [56; 47] attempted to prepare logical conjunctions between concepts and relations in the sake of knowledge representation [49]. Figure 1 shows the conceptual graph for the sentence "John is going to Boston by bus". The rectangles are called concepts, and the circles are called conceptual relations. An arc pointing toward a circle marks the first argument of the relation, and an arc pointing away from a circle marks the last argument.

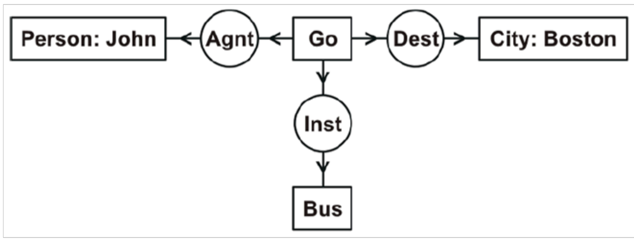

Figure 1: Conceptual graph (CG) displays form for John is going to Boston by bus

The conceptual graph in Figure 1 represents a typed or sorted version of logic. Each of the four concepts has a type label, which represents the type of entity the concept refers to Person, Go, Boston, or Bus. Two of the concepts have names, which identify the referent such as John or Boston. Each of the three conceptual relations has a type label that represents the type of relation which includes "Agent" (Agnt), "Destination" (Dest), or "Instrument" (Inst). The conceptual graph as a whole indicates that the person John is the agent of some instance of going, the city Boston is the destination, and a bus is the instrument [48]. Subsequently, the main elements of the mentioned conceptual graph comprise of "Concepts", "Proper names" and "Type labels", which logically conjunct with one another by "Arcs" to create logical order between arguments via arcs arrowhead.

In analyzing the graph structure or representation of ontologies, taxonomical or hierarchical structure [49] expressing 'is-a' relation has been taken into account to be considered as the most appropriate and common area [62] to evaluate the structure of ontologies. For instance, the role of conceptual graph in indicating generic concept for a type (e.g., mammals) or a concept may represent a specific object (e.g., Cat) [49]. Moreover, a few number of structural analysis methods were also expanded to evaluate other sorts of relationships in graph structure of ontologies, Reference [9] for instance, non-taxonomic relations [63] to indicate non-specified entities (i.e., associative relation) such as “Eat” and “Food” based on conceptual graph [49]. Therefore, structural dimension and analysis are limited to graph-dependent approach in evaluating taxonomic relations, partly non-taxonomic relations in ontology evaluation.

4.2. Identification of graph-independent structural analysis

As stated previously, the structural dimension is involved in evaluating ontologies when the research attempts to analyze the graph representation [10], graph structure [43] and a set of graph nodes [9] based on conceptual graph (CG) [48]. This notion is a graph-dependent approach in structural ontology evaluation. However, there are some structural domains in ontologies which cannot be evaluated by the graph-dependent approach. Although these structural domains are present in the conceptual graph, they can be identified through another perspective by breaking down the graph representation and its components. Therefore, for clarification of these structural domains, they will no longer be investigated in the form of the graph representation and this can be further realized through describing a basic example which help characterize the main elements and components of the conceptual graph without considering their graphical relations or arcs (i.e., relational graph).

The most basic example to characterize the main elements of graph representation based on a relational graph was proposed by Peirce [53; 54; 55]. Peirce’s works have been much further formalized as a refined version by Sowa [48; 56; 57] which consists of a basic and simple clarification for the significant idea of conceptual graph in formalizing and extending semantic network in the structure of ontologies [49]. Figure 2 presents conceptual graph in the form of relational graph [48] for the sentence, “Prof. Dr. John Smith is going to Boston University by Super-fast train”. In this case, the relational graph for this sentence includes some concepts and conceptual relations as well as their conjunction.

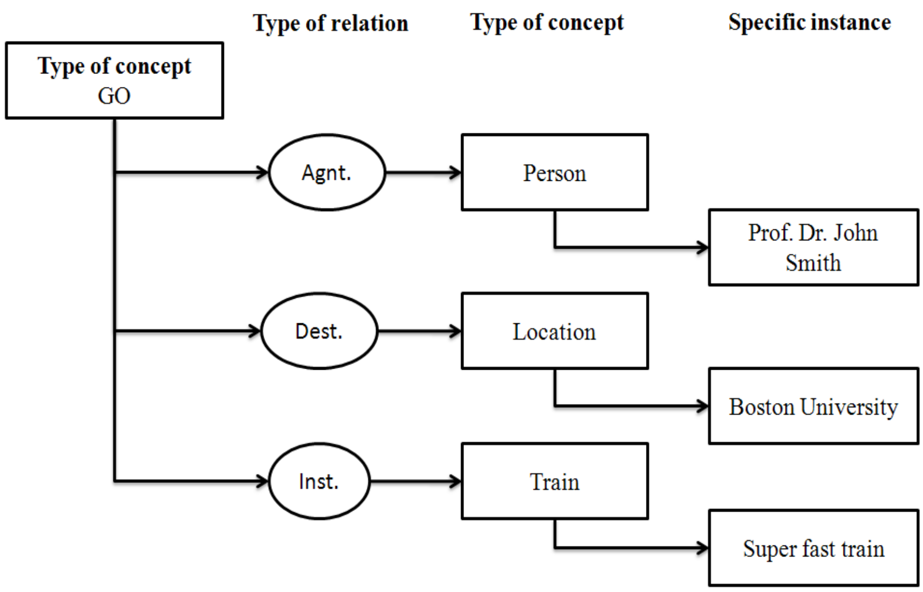

Figure 2: Relational graph for Prof. Dr. John Smith is going to Boston University by Super fast train

Figure 2 demonstrates the relational graph for the sentence "Prof. Dr. John Smith is going to Boston University by Super-fast train" based on conceptual graph. The rectangles are called concepts, and the circles are called conceptual relations. In the mentioned sentence, arcs represent the logical conjunction between concepts and conceptual relations to identify arguments and their priority [48]. There are four types of concepts in this relational graph (i.e., Person, Go, Location and Train). Furthermore, a concept may also have a specific referent or individual. A concept in a conceptual graph may represent a specific instance of that type, e.g., Super-fast train, is a specific instance, or individual, of type Train [49]. Thus, there are three specific instances, i.e., Prof. Dr. John Smith, Boston University and Super-fast train, in this relational graph. Moreover, three conceptual relations have their specific type label that represents the type of relation: Agent (Agnt), destination (Dest), or instrument (Inst). Consequently, conceptual graph in the form of the relational graph prepared logical conjunction between four types of concepts, three specific concepts and three conceptual relations to semantically arrange arguments in representing a logic-base graph [48] for formalization and extension of semantic network in the structure of ontology [49]. The power of logical conjunction as implemented in conceptual graph [49] plays a great role in linking two nodes [48] as being related in a graph [9]. In other words, two types of nodes which are comprised of a variety of concepts and conceptual relations can be merely linked with one another [48] via logical conjunction to represent a conceptual structure that is based on conceptual graph in extending of semantic network in ontologies [49]. In this sense, arcs represent the logical conjunction between concepts and conceptual relations in a relational graph based on conceptual graph [48]. In this matter, if the logical conjunctions or arcs were omitted between concepts, type of relation, type of concept and specific instances in figure 2 would be separated from each other forming independent domains. Therefore, the independent domains are formed when the main element of a graph structure which is the logical conjunction between concepts showing their conceptual relations in a conceptual graph, is removed. These remaining components which are now separate concepts and type of relations would no longer bear the meaning of graph. As stated previously, when logical conjunctions between concepts and conceptual relations were removed, the remaining components would be independent domains, i.e., separate concepts and type of relations. Separate concepts and the type of relations (i.e., independent domains) which no longer bear the meaning of graph can be analyzed based on a novel branch in structural analysis. These independent domains cannot be involved in the notion of a graph representation or graph-dependent approach based on conceptual graph in analyzing the structural evaluation of ontology. Table 5 shows the independent domains, i.e., type of relation, type of concept and specific instances which were previously presented as a relational graph in Figure 2 for the sentence "Prof. Dr. John Smith is going to Boston University by Super-fast train".

Table 4: The independent domains in the structure of ontologies

Type of relation	Type of concept	specific instances
Agent	GO	Prof. Dr. John Smith
Destination	Person	Boston University
Instrument	Location	Super-fast train
	Train	

Table 4 presents the remaining components of relational graph (Figure 2) after the main element (i.e., logical conjunction between concepts and conceptual relations) had been removed from the relational graph. These remaining components can be taken into account and identified as independent domains in ontology. These independent domains can be sorted into three categories; type of relation, type of concept and specific instances. These categories of the independent domains and their members provide various access points for identification of factors responsible for structural ontology evaluation. Moreover, this breaking down of conceptual graphs could interest ontology builders in constructing new ontologies by allowing them to pinpoint the strength and weaknesses of a previous ontology with respect to the amount of type of relation, type of concept and specific instances used. The mentioned categories and factors are useful in analyzing the structure of ontology based on a graph-independent approach. Graph-independent structural analysis has a capacity to evaluate the structure of ontology with regard to independent domains in the structure of ontologies. Some of the areas which can be analyzed through graph-independent structural analysis as well as some of the related examples (Table 4) are mentioned as follow:

1. Analyzing the interest of the ontology builders in constructing an ontology in terms of type of relations. Type of relations, are informative access points, showing the emphasize of an ontology on relations between concepts. These emphasizes may be useful when selecting an ontology between other alternatives which could be done by considering the usage of different type of relations. In a similar sense this usage of type of relations can be a measure of the structure of semantic relations by clarifying the emphasize of the ontology on different of type of relations. For instance, identifying the domain of type of relations such as “Instruments”, “Destination”, “Causes”, “Effects” … via counting the number of each type of relation.

2. Comparing the domain size (Number of agents, number of destination and so on) of various types of relations to clarify the core type of relations in ontology. By indicating the number of various types of relations it could be shown what the ontology builders have emphasized on, whether it was the “Influence” of something or something “Composed by” something or something “Causes” something and so on.

3. Finding common points between the domains of various types of relations through identifying common concepts between various types of relations that characterizes the core concepts or clusters in ontology structure. For instance, an ontology could include three type of relations such as “Instrument”, “Transport” and “possession”. “Instrument” might involve concepts like bus, bicycle and car. “Transport” involves plane, bus and car. The type of relation “Possession” includes bicycle, plane, and car. Here “Car” is the common point or the core concept between the three mentioned types of relations in our sample ontology.

4. Demonstrating the emphasizes of ontology on type of concepts or specific instances, and showing whether the structure of ontology comprises of generic concepts or more specific ones such as a specific name for example, ontology might have focused on “Location” as a type of concept or specific instances like “Boston university”.

5. Recognizing the domain of specific instances to determine the amount of proper nouns in ontology, for example, counting the numbers of specific instances such as "Boston" and "John" to analyze and measure if the ontology is overloaded or has chosen to emphasize on proper nouns or instances.

6. Specifying the domain of semantic relations (i.e., taxonomic and non-taxonomic relations) in ontology, for instance, determining the amount of taxonomic relations via counting the number of "is_a" relations.

7. Calculating the amount of semantic relation which each concept sent and received in the semantic network. For example, "Train" is a kind of "Transportation" instrument. Here "transportation" is a generic concept. There are several kinds of trains such as "Fast train", "Super-fast train" or "Express train". These are specific concepts for kinds of "Train". Thus, "Train" receives one generic concept (Transportation) and sends three specific concepts. In other words, structural analysis in a graph-independent approach has a capacity to compute concept inputs and outputs.

8. Analyzing the structure of concepts with regard to the number of words in their structure, for the realization of possible roles of the concept's structure in improving information retrieval performances, for instance, "Train" is a one-word concept and "Super-fast train" is a three-word concept. Previous research done on thesauri evaluation has shown that one-word descriptors are linked to more concepts compared to compound descriptors [64].

9. Preparing an infrastructure in comparing the structural domains with each other, like comparing concept structure with semantic relations to identify the possible roles of the structure of concepts in increasing or decreasing semantic relations in ontology.

5. Conclusion

Diverse tools, application and methods have been proposed for selecting the most suitable ontology. The results showed that the considered tools, applications and methods focused on the evaluation of different areas instead of assessing the ontology as a whole. However, they can be classified based on their approaches, categories and dimensions in similar groups. OntoClean and OntoMetric are the two influential ontology evaluation methods that target the majority of the approaches in ontology evaluation especially, structural evaluation. In spite of the importance of the structural analysis, the majority of literatures focus on functionality and usability issues. Therefore, ontology evaluation researches should focus on structural dimension and analysis in establishing a balance between investigations in all the dimensions in evaluating ontologies.

Structural analysis is limited to conceptual graph in evaluating ontologies. Concepts and conceptual relations can be linked with one another via logical conjunctions based on conceptual graph in semantic network. This idea is called the graph-dependent approach in expressing semantic network in ontologies. In this matter, if the logical conjunctions were omitted between concepts and conceptual relations, these nodes and relations would be separated from each other forming independent domains. Therefore, when the main element of graph structure or conceptual graph, which is logical conjunction between concept and conceptual relations were removed, the remaining components which are separate concepts and conceptual relations would no longer bear the meaning of the graph.

In conclusion, the separate concepts and conceptual relations, which would no longer have the meaning of graph based on Conceptual Graph, can no longer be involved in the notion of the graph-dependent approach. In this manner, there is a gap in analyzing the ontology structure. In this case, the graph representation and graph-dependent approach will not be the only approach in evaluating the structure of ontologies. Thus, there is lack of a novel branch in structural analysis which we call as the Graph-independent approach. In this case, there are several graph-independent areas in the structure of ontologies which can be evaluated based on the structural dimension. These structural domains are the structure of concepts and semantic relations domains. Thus, graph-independent structural analysis as a novel branch in structural analysis has a capacity to evaluate the structure of ontology with regard to independent domains in the structure of ontologies.

6. Recommendations

Some of the recommendation areas in analyzing the structural analysis based on graph-independent approach in ontologies were mentioned in section 4.2. In this section, three groups of recommendations are identified as the specific domains in assessing the ontology structural analysis and are mentioned as follow:

1. Operating proportional analysis as statistical method on evaluating the structure of concepts.
2. Developing specific criteria and the related identifiers to measure the domains of semantic relations in ontologies.
3. Clarifying and operating the methods to weigh the usage of semantic relations in semantic network in ontologies.

The mentioned recommendations can be taken into account as research topics in evaluating the structure of ontologies for developing future studies with the following aims:

1. Proposing indices based on the specific criteria and indicators to measure concept structures in ontologies.
2. Analyzing integration and association in the semantic network in evaluating the domain of taxonomic and non-taxonomic relations in ontologies based on the related indices.
3. Measuring the core semantic relations in comparison with the peripheral semantic relations in semantic network of ontologies.

7. Limitations

The researcher has worked as information organizer for twenty five years in the field of Library and Information Sciences (LIS). During these practical experiences, the researcher has found that the structure of descriptors play an extraordinary role in information storage and retrieval in terms of recall and precision rates. Analysis of concepts structure can be taken into account as a kind of structural analysis in ontologies as well. Furthermore, semantic relations demonstrate spectacular behavior when they are listed in an alphabetical order in various kinds of controlled vocabulary such as subject heading, thesauri and so on. In this case, the domains of the subject fields can be recognized in information centers, especially when the numbers of similar semantic relations have been taken into account in identifying their specific domains. According to different families of knowledge organization systems, including thesauri, classification schemes, subject heading systems, taxonomies and ontologies, the mentioned idea about semantic relations can be operated in identifying semantic relations domains in ontologies. The behaviour analysis of the aforementioned structural domains was the starting point to carry out investigation on structural domains in thesauri when the author was accepted as LIS Ph.D candidate in 1999 [65]. Consequently, the analysis of characteristics and specification of descriptors structure (i.e., concepts) and semantic relation domains comprise of the new phenomenon in this study in evaluating ontologies with regard to structural analysis.

The mentioned experiences and ideas in ontology evaluation which are derived from information organizing and thesauri evaluation can be taken into account as strong points in the research area. However, the author had to move from LIS to technology area to operate the novel idea in ontology evaluation when the author was accepted as Knowledge Technology and Management Ph.D. candidate in 2009 [40]. This situation required the achievement of various qualifications in the new research domain which caused some issues. Firstly, there was lack of common language between LIS and Technology area, secondly, the identification of novel idea in knowledge representation comprised of various difficulties because the ideas came from LIS area, and finally, the justification of theoretical and critical thinking of information storage and retrieval in operating the structural analysis of ontology evaluation faced some difficulties when it came to convince technology scientists.

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