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An Approach for Evaluating & Ranking Ontologies with Applications in Biomedical Domain

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Abstract- Since last few decades, the biomedical ontologies are being developed from numerous knowledge bases and these ontologies act as an effective mean of organizing medical knowledge. Ontologies play a significant role in the structural organization of the available medical information that enable efficient knowledge discovery and access in many biomedical applications. Recently, due to abrupt expansion in biological data and knowledge in the form of biomedical ontologies, the attention of their usefulness increases in research. Meanwhile, there are some challenges of accurately building and maintaining ontologies so that their benefit of re-usability in the respective fields can be implemented. The evaluation of ontologies is an open research problem due to the complexity in their structure. Keeping this in view, in this research study, we aim to investigate the reuse and applications of these ontologies. To achieve our research goal, the proposed approach is designed on the core building blocks such as concepts, classes, sub-classes, super-classes, instances/ individuals of classes, triple components including subjects, predicates, objects and different properties. When domain knowledge is combined with these structural components, it generates a well-structured ontology. The performance of proposed research elaborates the structural strength in a comprehensive way.

Keywords- Biomedical ontologies, Knowledge discovery, Ontology applications in biomedical domain, Ontology web language, Ontology evaluation.

I. INTRODUCTION

Ontology is concerned with the study of what exists and is a formal specification of domain conceptualization [1]. In the literature, ontology is comprehended as a metaphysical study of nature, basic attributes of individuals and their inter-relations [1]. Ontology is applied to elaborate the domain terminologies, association links and properties [2]. Since 1990, ontologies play a noteworthy role in the field of information sharing [3]. In fact these ontologies take hold of real world information. Ontology is represented as an approximation of domain specification and ontology evaluation represents degree of approximation (as shown in Fig. 1). The key perspective of ontologies is their structure and capability to act accordingly for the desired purpose [3, 4].

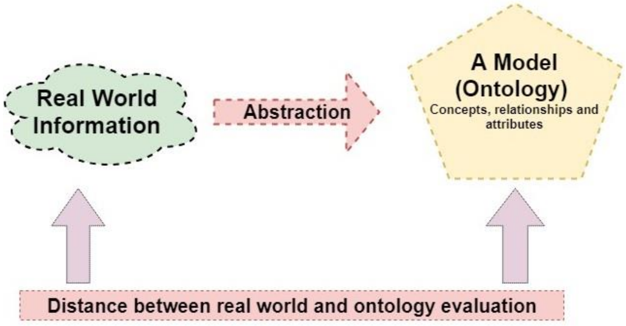


Fig. 1: Notion of real world ontology and ontology evaluation

With respect to structural aspects, ontologies are taxonomic hierarchical tree showing generic concepts at the top of the tree [3]. The domain specific ontology can be composed manually by adding concepts and relationships between them in a well-organized form [5]. The structure of ontology is described in a way that it is a combined set of categories (concepts, classes), relationships, attributes (properties), constraints and individuals (instances) [1, 6] (as shown in Fig. 2). Ontologies are used for various purposes including knowledge management, information extraction, data integration and in semantic web [2]. The proposition of applying semantics through ontologies gives rise to the significant impact on software industry [7]. Furthermore, the clinical decision support systems are programmed using ontologies and decisions are used after necessary reprocessing [8]. More specifically, biomedical ontologies are applied by medical researchers for analysis of biomedical data and gathering of information for decision support systems for predictions and data assimilation [9]. Ontology evaluation is an essential element for ontology development and maintenance as it can enhance the reusability [6, 10]. According to literature, various techniques for ontology evaluation are proposed for different applications [1, 2, 11]. Along with other evaluation techniques, structure oriented evaluation approaches are necessary to ensure structural strength of ontology as it determines the application requirements and can assist about decisions about the use of inspected ontology [12].

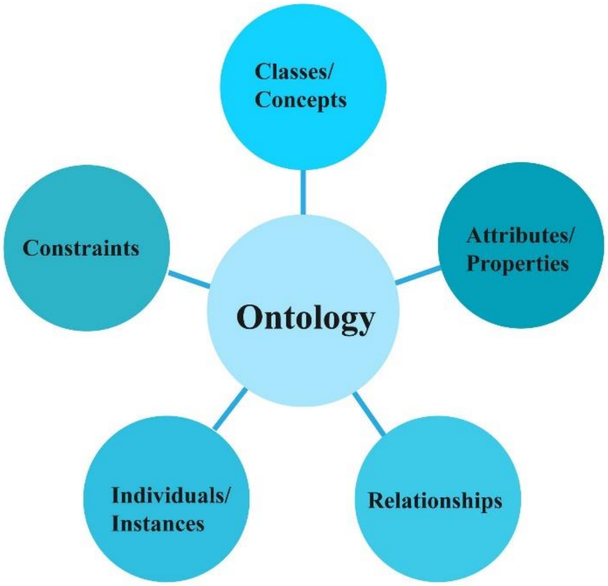


Fig. 2: Structure of ontology

The medical knowledge is a bit complicated as this is becoming the most vital information source for mankind. The combination of various biomedical ontologies attempts to represent biomedical data through different approaches [1, 13, 14]. A range of biomedical ontologies have been found in literature and web such as Bilingual ontology of Alzheimer's Disease and Related Diseases (ONTOAD) [15], Ontology for Genetic Susceptibility Factor (OGSF) [16], Genomic Clinical Decision Support Ontology (GENE-CDS) [17], Radiation Oncology Ontology (ROO) [18], Ontology of Core Data Mining Entities (ONTODM-CORE) [19], Autism Spectrum Disorder Phenotype Ontology (ASDPTO) [20], Alzheimer's Disease Ontology (ADO) [21], Human Physiology Simulation Ontology (HUPSON) [22], Semantic DICOM Ontology (SEDI) [23], Microarray and Gene Expression Data (MGED) Ontology [24], Gene Ontology (GO) [25], Systematized Nomenclature of Medicine-Clinical Terms (SNOMED) [26], National Cancer Institute (NCI) Thesaurus [24] and Functional Genomics Ontology (FuGO) [27]. The applications and reuse of ontologies in various fields of knowledge engineering provide a base to evaluate them [3].

Following below are two applications of ontologies in biomedical domain. In [28], authors suggest a smart health diagnosis technique which uses web-based personal health record services and automatically produced ontology. The proposed system initially produces a human disease diagnosis ontology by using two reputable ontologies for diseases: an open biomedical repository and a large-scale medical bibliographic database. According to [29], authors device an application in gene clustering using Gene Ontology. In this application biological knowledge is extracted from Gene Ontology to produce multi-factored gene-gene proximity measures. Gene Ontology has numerous applications in the field of bioinformatics like identifying genes/proteins by their GO annotations for disease gene, measuring gene-gene or protein-protein semantic similarity and target discovery.

Both qualitative and quantitative based ontology evaluation approaches for evaluating biomedical ontologies have been proposed. The existing research do not present the low-level details of structural components such as classes/concepts, relations and other structural constructs [1]. The process of evaluating biomedical ontologies is difficult due to diverse domains, intended purposes, building languages and there is no standard evaluation approach [3]. In an attempt to overcome these limitations, the proposed methodology has assessed the quality of biomedical ontology from the perspective of structural components based on the structural parameters that are classes, properties and triples. Therefore, the main contribution of this paper is to integrate these parameters for the quantitative evaluation of bio-medical ontologies to analyze the parameter richness of each ontology. The proposed work has novelty in it. In the proposed framework the combination of basic constructs which are used for evaluation of ontologies are unique in their nature. The selected evaluation parameters are not used still in any existing published research work. However in [30], authors propose a methodology to automatically constitute ontology modules into a global ontology. This a methodology is based on similarity measures calculated against concept names, attributes and relationships. They also merge the ontology modules into a global ontology. The performance of proposed research elaborates the structural strength in a comprehensive way.

The section II describes the related work in the area of evaluation of biomedical ontologies. Section III presents the proposed methodology. Afterwards the section IV illustrates the results of experiments obtained by applying proposed methodology along with comparison with other existing methodologies. The last section is about conclusion, pros and cons with the future directions for research.

II. RELATED WORK

For the purpose of evaluating ontologies, the first step is to go through the process of building them [6, 31, 32]. As stated in [31], ontology is a way of organizing information in an optimum way. Keeping this in mind, the structure of ontology is the first step is to fabricate the frame. In the second step essential concepts and terms are extracted from the domain. Then concepts are inter-linked with each other through relations. The instances or individuals of concepts are elaborated. Afterwards ontology is formalized and coded. To evaluate the effectiveness of approach, in the last step ontology is evaluated and verified. Various approaches of evaluating ontologies are devised, the core methodologies are mentioned here. In Golden standard approach, ontology is judged against a standard named as “gold standard” as it is considered to be well built reference ontology [1, 6]. In other words, it acts as a benchmark for ontology evaluation. Task-based evaluation is also known as “application-based evaluation”. In this approach, the ontology is assessed corresponding to its applicability and usefulness in certain applications [33]. As various applications have context from different domain, so what is appropriate in one context may not be appropriate for other. In data driven ontology, evaluation approach ontology is compared against data available in the domain models [27]. It involves the equivalency check between the content of ontology and existing domain knowledge. Certain evaluation approaches consider the popularity of ontology among their collection. OntoKhoj approach [34] applies OntoRank algorithm for the evaluation of ontologies. This algorithm considers semantic links between ontologies and comprises of instantiation and sub-sumption.

Multi-criteria based evaluation employs manifold facets for assessing the quality of ontologies. This type of evaluation collects various types of statistics about the domain knowledge available in ontology by inspecting the ontology. In [35], the authors advise to evaluate the ontology on quantifiable and non-quantifiable characteristics. This methodology is based on importing ontologies through web crawling and saving them in the database. An approach named as Ontometric [36] is a multi-facet methodology. This method requires the application to be provided by many values which are utilized to express the appropriateness of ontology. Another approach named AKTiveRank [37] locates related ontologies against the term entered by user. This technique used four metrics for evaluating ontologies. The metrics include semantic similarity, density and class match. The authors in [38], established a tool named ODEval that can automatically identify the syntactical problems in ontologies. OntoClean [39], is a methodology of evaluating and validating ontology, is proposed which is based on features including Unity, Rigidity, Identity and Dependence. These features are assigned by user to each class of ontology. Set of rules are generated based on these four features against which classes are inspected, whether these classes violate the rule or not. Based on these rules classes can be added or removed to correct the discovered problems. The authors in [40], evaluated the ontologies on the metrics of validity, soundness, coverage of domain including granularity, richness and complexity of coverage, completeness, consistency, reusability and adaptability, inference ability, mappability to other ontologies and finally evaluation against requirements, use cases and data sources [40]. In [41], ontologies are evaluated against the criteria of transparency of analyzing ontology in detail, cognitive ergonomics of easily comprehension and manipulation of ontology. Florian and Patrick [42] organized ontology evaluation process with respect to complexity, evaluation method and approach strategy. In [43], the proposed an evolution based technique for evaluating ontologies. Rule based evaluation methodologies are based on rules built in the ontology languages. These rules fundamentally track conflicts in the ontologies [44].

In [45], Full Ontology Evaluation (FOEval) is proposed that is based on four structural ontology features. These features include coverage, richness, detail-level and comprehensiveness. FOEval approach [45] also partitions available ontology evaluation approaches into four groups: what should be evaluated, when it should be evaluated, and lastly based on what it should be evaluated. In [41], structural meta-ontology approach is presented for the purpose of classifying ontologies into structurally similar families, so that consistent evaluation methods can be applicable. According to [46], an error agnostic approach based on lattice structure was developed for auditing ontologies and relies on order structure induced by hierarchical relationships. OntoCAT approach uses comprehensive collection of metrics for evaluating ontology for the purpose of their reuse in other applications [47]. The authors in [44], expressed ontology evaluation from the perspective of correctness, ranking, quality and software engineering. OntoQA (Ontology Quality Assurance) [35] is a feature-based ontology evaluation tool. The metrics of OntoQA are divided into two categories: instance metrics and schema metrics. The experiments are conducted on three ontologies; Glyco, TAP and SWETO. In [48], the authors present a web-based tool OntoKeeper which can measure the quality of biomedical ontologies for ontology developers. In this tool five practiced ontologists are enlisted who evaluates the usability results of OntoKeeper. OntoKeeper is based semiotic measures Burton-Jones and colleagues. Both syntactic calculations and semantic calculations are shown by OntoKeeper. Furthermore pragmatic calculations are also considered by gathering the number of instances, classes, object properties and data properties. In [49], the authors have proposed prototypical ontology based evaluation system for pile integrity (OntoPIE). Furthermore a structure of leverage knowledge modeling is created to build user friendly tool for quantitative measurement of pile faults. Along with quantitative measurement, qualitative assessment of pile integrity is also done by joining ontology and rules of semantic web language. Precision of proposed evaluation framework is also tested by equating the numerical indicators of pile defects inferred by OntoPIE with stipulated defect indicators through examples. In [50], ontology evaluation is defined in the context of two concepts; validation and verification. According to [50], building the correct ontology is ontology validation and building the ontology correctly is ontology verification. From this definition classification of ontology evaluation endeavor gets possible. In his work he says that objective of ontology evaluation must not to work well for all criteria and also advocates that some evaluation criteria may even be conflicting.

In [51] hierarchical relations between the ontological concepts are deduced along with the representation of logical definitions with respect to lexical characteristics of names of concept in Web Ontology Language (WOL). In [52], the authors proposed an ontology named as Requirement Change Ontology (RCO) for requirement change management in global software development environment. Web Ontology Language (OWL) is used for demonstration of proposed ontology and for implementation Protégé is used. For the purpose of verification FOCA and ontology taxonomy evaluation methods are used. This ontology is useful for software engineering as well as for fields of knowledge management. RCO is used to make sure the semantic accuracy of change demands and increase their reliability. In [53], the authors propose an ontology for enlightening the surveillance of adverse childhood experiences (ACEs). The main purpose of developing this ontology is to offer a uniform structure to show the existing studies on the causes, effects, mitigation and prevention of ACEs. ACEs is publicly available in BioPortal repository. This ontology can be used by mental health researchers and practitioners to enhance ACEs surveillance and evaluation. In [54], an algorithmic technique has been developed to visualize and summarize the structural variations during the advancement of biomedical ontologies. To test the semantic types [55], a cross-validation approach of the Unified Medical Language System (UMLS) concepts is used. In [56], diabetes related text corpora from social questions-answers forum is being used for assessing the conceptual coverage of SNOMED-CT. Being a challenging data field, biomedical ontologies are blended together including their building and modeling techniques [57]. According to [58], a scalable framework is proposed to test the semantic completeness of SNOMED-CT. One approach found in literature with title Ontobee [59] extracts the statistics of ontologies. It is web-based system that retains the statistical record of about 128 ontologies. In Ontobee repository, ontologies are presented as linked data. Similarly ontologies have been evaluated against extrinsic and intrinsic methods [60]. In our presented work, biomedical ontologies are evaluated against structural components. Our evaluation criteria metric includes the population of concepts, instances, triples (subject, predicate and object) and properties (annotation, data, object, reflexive, symmetric, asymmetric and functional).

III. PROPOSED METHODOLOGY

This section is about the proposed methodology that is used for the evaluation of the proposed research. The detail about system architecture, data gathering, Ontology Web Language (OWL), Protégé, SPARQL, evaluation methodology and selected criteria are mentioned in the following sections.

System Architecture: The work flow of the proposed methodology is shown in Fig. 3. In the first step, the biomedical ontologies related to the same domain are gathered. Then these gathered biomedical ontologies are imported in ontology editor named Protégé. These ontologies are imported from an ontology library named as OBO BioPortal. National Center for Biomedical Ontology (NCBO) is created by BioPortal, which is one of the largest repository and development system for biomedical ontologies [61]. After importing ontologies SPARQL queries are executed on imported ontologies for digging through various structural characteristics. From these executed queries, the relative count of each characteristic is obtained and on the basis of these results, the best appropriate ontology is selected.

Data Gathering: For experimental purpose, total of twenty three biomedical ontologies are imported in Proteg´e from The Open Biological and Biomedical Ontologies. Three of the imported ontologies are from the domain of anatomy, two of them are from neuroscience domain, two from the field of medicine, two ontologies from biomedical experimental domain, two from medical statistics, two from chemical domain, two from cell domain, two from drug domain, two from gene domain, two from physico-chemical and two from ribonucleic acid (RNA). Table 1 presents the details about ontologies. All ontologies exist in two comprehensive repositories of biomedical ontologies; BioPortal [62] and The Open Biological and Biomedical Ontology (OBO) Foundry [63].

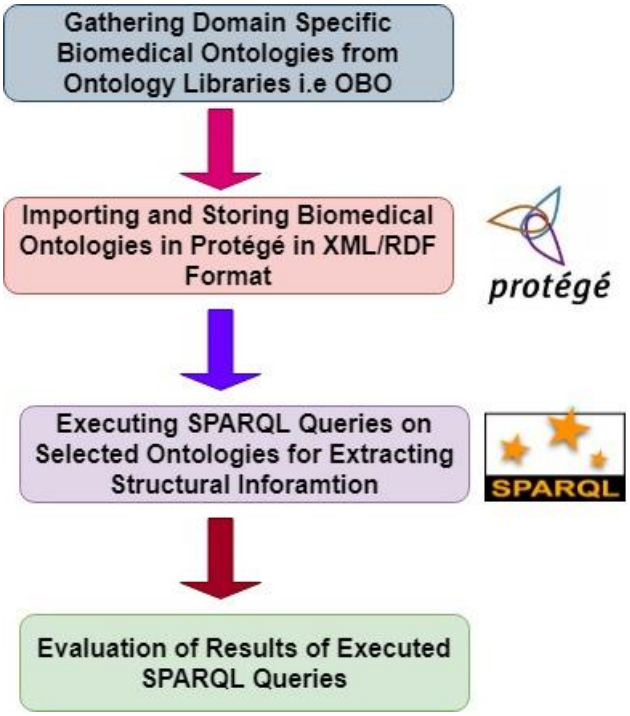


Fig. 3: The steps of Proposed Framework

Ontology Web Language (OWL), Protégé and SPARQL: Protégé is one of the convenient and practical approach for building an ontology from scratch. Protégé also acts as an ontology editor with OWL and RDFS. Protégé 4.3 version is used in our research and experimentations. It offers the facility of composing various types of ontologies using graphical user interfaces (GUI) including options for adding classes, sub-classes, entities, object properties, data properties, annotation properties and individuals [64]. Ontology Web Language (OWL) is a standard formal language for representing Semantic Web knowledge. One important aspect of OWL is that it can characterize both the reasoning knowledge and domain knowledge by using the constructs of class definitions and axioms [61]. SPARQL is an extremely useful querying and reasoning language that gives effortless access to general classes/concepts, attributes/properties and annotations of dataset i.e. ontologies [45]. Due to immense power of queries, it exposes the structural characteristics of OWL based biomedical ontologies [64].

Table 1: Selected biomedical ontologies

Ontology Title	**Domain**	**File**
Uber Anatomy Ontology (UAO)	Anatomy	ext.owl
Porifera Ontology (PO)	Anatomy	poro.owl
Hymenoptera Anatomy Ontology (HAO)	Anatomy	hao.owl
NIF Cell (NIFC)	Neuroscience	NIF-Cell.owl
NIF Dysfunction (NIFD)	Neuroscience	NIF-Dysfunction.owl
Ontology for General Medical Science (OGMS)	Medicine	ogms.owl
Ontology for Medically Related Social Entities (OMRSE)	Medicine	omrse.owl
NMR-Instrument Specific Component of Metabolomics Investigations (NMR)	Experiments	NMR.owl
Microarray Experimental Conditions (MEC)	Experiments	MGEDOntology.owl
STATistics Ontology (SO)	Statistics	stato.owl
Ontology of Biological and Clinical Statistics (OBCS)	Statistics	obcs.owl
Chemical Information Ontology (CIO)	Chemical	cheminf.owl
Chemical Entities of Biological Interest (CEBI)	Chemical	chebi.owl
Cell Ontology (CO)	Cell	cl.owl
Cell Line Ontology (CLO)	Cell	clo.owl
The Drug-Drug Interactions Ontology (DINTO)	Drug	dinto.owl
The Drug Ontology (DRON)	Drug	dron.owl
Gene Ontology (GO)	Gene	go.owl
The Ontology of Genes and Genomes (OGG)	Gene	ogg.owl
Physico-chemical methods and properties (PCMP)	Physico-Chemical	fix.owl
Physico-chemical process (PCP)	Physico-Chemical	rex.owl
microRNA Ontology (MRNAO)	RNA	miRNAo.owl
Ontology for MIRNA Target (OMT)	RNA	omit.owl

Evaluation Methodology and Rationale of Structural Evaluation of Biomedical Ontologies: Open Biological and Biomedical Ontologies (OBO) is selected among different ontology libraries because it includes wide-range of biomedical ontologies. The detail of each ontology can be viewed through OBO web portal. For experimentation purpose, these ontologies are imported which are developed in Ontology Web Language (OWL). In an attempt to find the most suitable biomedical ontology, one way is to select ontology which encompasses certain intensity of data illustration concerning specific domain [65]. Data illustration is described as concentration of concepts, properties among these concepts, triples and annotations. Consequently, significance of the role of structural components including classes or concepts, instances or objects, individuals, relations or properties and triples for evaluation of biomedical ontologies is proved [9]. The physical appearance of ontologies is hierarchal tree and comprises of data components including concepts arranged as nodes of interconnected relations [66]. Similarly in biomedical ontologies there is a core position of concepts and relations among them [67].

Selected Criteria: According to [68], Ontology Web Language (OWL) based ontology comprises of classes/concepts, individuals/instances and properties/relations as major building blocks. So in our proposed evaluation methodology of biomedical ontologies, we have chosen these three major components along with the triple density.

Extraction of Results: We have applied SPARQL queries by using Protégé and for the sake of readability, we restrict ourselves to present some of the queries. Fig. 4 represents the proposed criteria for the evaluation of biomedical ontologies while Fig. 5 represents the experimental queries used for the extraction of results.

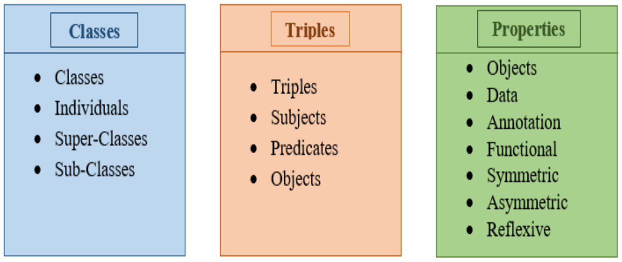
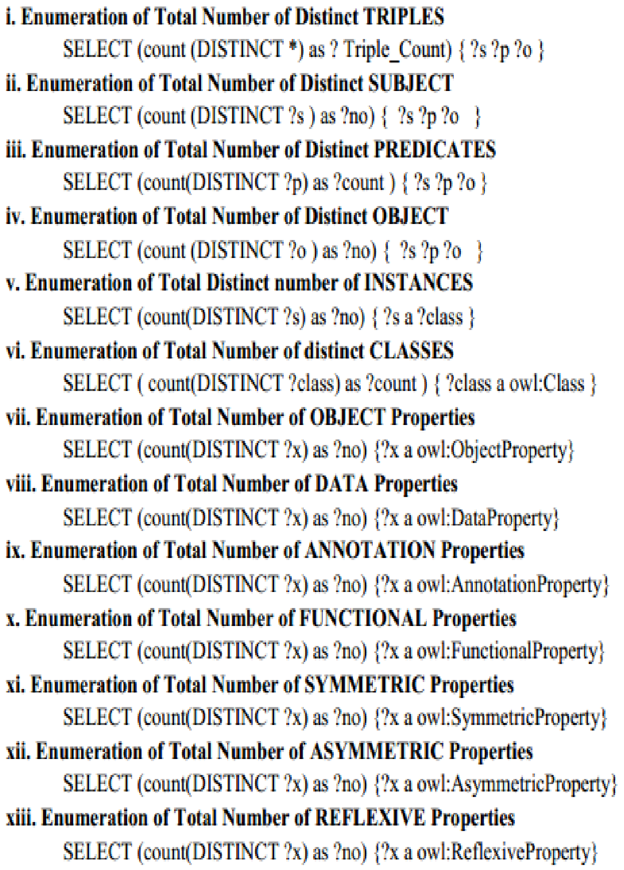


Fig. 4: Proposed criteria for the evaluation of biomedical ontologies

IV. RESULTS AND DISCUSSION

After executing respective SPARQL queries on ontologies, results are computed. Table 2-3 represent the comparative triple population density of biomedical ontology. Table 4-5 represent a comparative population density of classes, super-classes, sub-classes and individuals or instances of biomedical ontologies. Table 6-7 represent the comparative density of properties/relations.



i. Enumeration of Total Number of Distinct TRIPLES

SELECT (count (DISTINCT *) as ? Triple_Count) { ?s ?p ?o }

ii. Enumeration of Total Number of Distinct SUBJECT

SELECT (count (DISTINCT ?s) as ?no) { ?s ?p ?o }

iii. Enumeration of Total Number of Distinct PREDICATES

SELECT (count(DISTINCT ?p) as ?count) { ?s ?p ?o }

iv. Enumeration of Total Number of Distinct OBJECT

SELECT (count (DISTINCT ?o) as ?no) { ?s ?p ?o }

v. Enumeration of Total Distinct number of INSTANCES

SELECT (count(DISTINCT ?s) as ?no) { ?s a ?class }

vi. Enumeration of Total Number of distinct CLASSES

SELECT (count(DISTINCT ?class) as ?count) { ?class a owl:Class }

vii. Enumeration of Total Number of OBJECT Properties

SELECT (count(DISTINCT ?x) as ?no) {?x a owl:ObjectProperty}

viii. Enumeration of Total Number of DATA Properties

SELECT (count(DISTINCT ?x) as ?no) {?x a owl:DataProperty}

ix. Enumeration of Total Number of ANNOTATION Properties

SELECT (count(DISTINCT ?x) as ?no) {?x a owl:AnnotationProperty}

x. Enumeration of Total Number of FUNCTIONAL Properties

SELECT (count(DISTINCT ?x) as ?no) {?x a owl:FunctionalProperty}

xi. Enumeration of Total Number of SYMMETRIC Properties

SELECT (count(DISTINCT ?x) as ?no) {?x a owl:SymmetricProperty}

xii. Enumeration of Total Number of ASYMMETRIC Properties

SELECT (count(DISTINCT ?x) as ?no) {?x a owl:AsymmetricProperty}

xiii. Enumeration of Total Number of REFLEXIVE Properties

SELECT (count(DISTINCT ?x) as ?no) {?x a owl:ReflexiveProperty}

Fig. 5: Experimental queries used for the extraction of results

Table 2: Comparative Triples Density of Biomedical Ontology

Ontology Title	Distinct Subject	Total Subject	Distinct Predicate	Total Predicate
UAO	380147	1752812	114	1752812
PO	11066	45846	60	45846
HAO	37919	153215	24	153215
NIFC	37470	143332	112	143332
NIFD	31287	132016	99	132016
OGMS	3747	16467	51	16467
OMRSE	5156	21172	61	21172
NMR	1403	4901	8	4901
MEC	6049	23753	40	23753
SO	10996	45705	60	45705
OBCS	7983	33104	44	33104
CIO	2121	9373	72	9373
CEBI	616079	4460029	38	4460029
CO	402243	374078	152	374078
CLO	69863	1387096	180	1387096
DDIO	222337	986607	73	986607
DO	1626476	5032122	56	5032122
GO	250710	1438096	47	1438096
OGG	70962	1211523	73	1211523
PCMP	1259	7647	16	7647
PCP	1004	5632	20	5632
MRNAO	782	4130	12	4130
OMT	87864	393365	20	393365

Table 3: Comparative Triples Density of Biomedical Ontology

Ontology Title	Distinct Object	Total Object	Distinct Triple	Total Triples
UAO	475374	1752812	1752812	1752812
PO	13417	45846	45846	45846
HAO	39910	153215	153215	153215
NIFC	45110	143332	143332	143332
NIFD	39171	132016	132016	132016
OGMS	4689	16467	16467	16467
OMRSE	5944	21172	21172	21172
NMR	1643	4901	4901	4901
MEC	7514	23753	23753	23753
SO	13373	45705	45705	45705
OBCS	36	33104	33104	33104
CIO	4505	9373	9373	9373
CEBI	1280402	4460029	4455279	4460029
CO	122840	374078	374050	374078
CLO	535731	1387096	1386659	1387096

DDIO	419130	986607	986406	986607
DO	1758988	5032122	5026542	5032122
GO	444978	1438096	1437584	1438096
OGG	432889	1211523	1211194	1211523
PCMP	3991	7647	7647	7647
PCP	2581	5632	5632	5632
MRNAO	2644	4130	4130	4130
OMT	215229	393365	393335	393365

Table 4: Comparative density of concepts/classes, instances and individuals

Ontology Title	**Distinct Super Classes**	**Distinct Subclass**	**Distinct Classes**
UAO	12	24902	24914
PO	8	970	978
HAO	4	2346	2350
NIFC	9	2977	2986
NIFD	6	2961	2967
OGMS	6	207	213
OMRSE	11	365	376
NMR	11	290	301
MEC	6	230	236
SO	7	969	976
OBCS	8	751	759
CIO	78	714	792
CEBI	13206	118843	132049
CO	752	9831	10583
CLO	934	43940	44874
DDIO	1367	26811	28178
DO	14299	436893	451192
GO	7908	41923	49831
OGG	6019	63669	69688
PCMP	87	1076	1163
PCP	35	517	552
MRNAO	54	622	676
OMT	2383	85433	87816

Table 5: Comparative density of concepts/classes, instances and individuals

Ontology Title	**Total Classes**	**Instances/ Individuals**	**Total Instances**
UAO	144658	123704	676504
PO	4636	3031	18249
HAO	16824	13991	65967
NIFC	10041	5616	51926
NIFD	9933	5585	50719
OGMS	806	1117	6312
OMRSE	1431	1062	8253
NMR	870	306	1902
MEC	1866	1302	10275
SO	4628	3002	18199
OBCS	3032	1556	13068
CIO	792	23	23
CEBI	132049	0	0
CO	10583	4	4
CLO	44874	41	41
DDIO	28178	0	0
DO	451192	19	19
GO	49831	0	0
OGG	69688	0	0
PCMP	1163	0	0
PCP	552	0	0
MRNAO	676	0	0
OMT	87816	0	0

Table 6: Comparative density of properties/relations

Ontology Title	**Object Property**	**Data Property**	**Annotation Property**
UAO	183	0	199
PO	50	0	49
HAO	4	0	15
NIFC	85	0	178
NIFD	83	0	169
OGMS	78	0	52
OMRSE	70	0	59
NMR	11	0	34
MEC	85	42	44
SO	48	4	28

OBCS	36	6	19
CIO	106	7	73
CEBI	9	0	36
CO	267	0	193
CLO	116	1	192
DDIO	72	17	94
DO	18	1	63
GO	9	0	50
OGG	81	0	44
PCMP	5	0	10
PCP	6	0	11
MRNAO	13	0	5
OMT	17	3	2

Table 7: Comparative density of properties/relations

Ontology Title	Functional Property	Symmetric Property	Asymmetric Property	Reflexive Property
UAO	0	6	0	0
PO	6	0	0	0
HAO	0	0	0	2
NIFC	3	4	0	9
NIFD	3	4	0	9
OGMS	2	0	0	0
OMRSE	10	0	5	0
NMR	0	0	0	0
MEC	8	0	0	0
SO	6	0	0	0
OBCS	9	0	0	0
CIO	8	5	0	0
CEBI	0	0	0	0
CO	1	7	1	0
CLO	0	1	0	0
DDIO	2	2	0	0
DO	0	0	0	0
GO	0	0	0	0
OGG	2	0	0	0
PCMP	0	0	0	0
PCP	0	0	0	0
MRNAO	0	0	0	0
OMT	0	2	0	0

Analysis of Experimental Results: We generalize the obtained experimental results in triples, classes and properties. Each category is given equal weight, in triples total number of subjects, predicates and object are summed up. Similarly under the category of classes, total classes and individuals are added and for properties, all specified biomedical ontology are added to get total properties count. At the end all classes, triples and properties are summed up to calculate total structural coverage of specific ontology and best one is suggested on structural basis.

Here we summarized the results with respect to categories of ontologies in tabular form. First we concisely summarized the results of biomedical ontologies related to Anatomy. In the second step we summarized the results of biomedical ontologies related to Neuroscience including NIF Cell and NIF Dysfunction. Then we summarized the results of biomedical ontologies related to Medicine including Ontology for General Medical Science and Ontology for Medically Related Social Entities. After summarizing the results of Medicine ontologies including NMR-Instrument Specific Component of Metabolomics Investigations and Microarray Experimental Conditions, results of Experimental medical ontologies are concisely discussed. Then we summarized the results of biomedical ontologies related to Statistic Ontology and Statistics including Ontology of Biological and Clinical Statistics. After this we summarize the results of Chemical Ontology including Chemical Information Ontology and Chemical Entities of Biological Interest. Then we summarize the results of cell ontologies including Cell Ontology and Cell Line Ontology. Afterwards we summarize the results of drug ontologies including Drug-Drug Interactions Ontology and Drug Ontology. After this we summarize the results of gene ontologies including Gene Ontology and Ontology of Genes and Genomes. Then we summarize the results of physico-chemical ontologies including Physico-chemical methods and properties and Physico-chemical process. Lastly we summarize the results of RNA including microRNA Ontology and Ontology for MIRNA Target.

As discussed in the section above, the summarized result of biomedical ontologies related to Anatomy domain is shown in Table 8 and results are summarized in Fig. 6. The result of neuroscience ontologies is shown in Table. 9 and Fig. 7. The result of medicine ontologies is shown in Fig. 8 and Table 10. The result of experimental ontologies is shown in Fig. 9 and Table 11. Fig. 10 represents the results of statistics ontologies.

Table 8: Result of anatomy ontologies

Ontology Title	Triples	Classes/ Individuals	Properties	Total
UAO	2608347	148618	394	2757359
PO	70389	4009	105	74503
HAO	231068	16341	21	247430

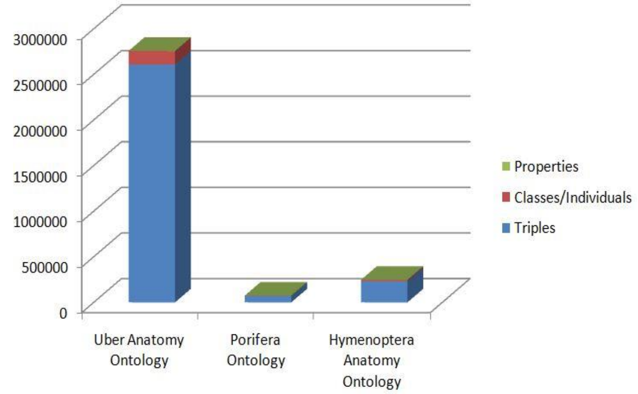


Fig. 6: Summarized result of anatomy ontologies

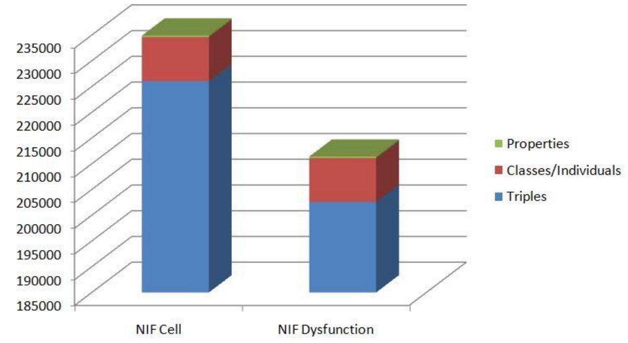


Fig. 7: Summarized result of neuroScience ontologies

Table 9: Result of neuroScience ontologies

Ontology Title	Triples	Classes/ Individuals	Properties	Total
NIFC	226024	8602	279	234905
NIFD	202573	8552	268	211393

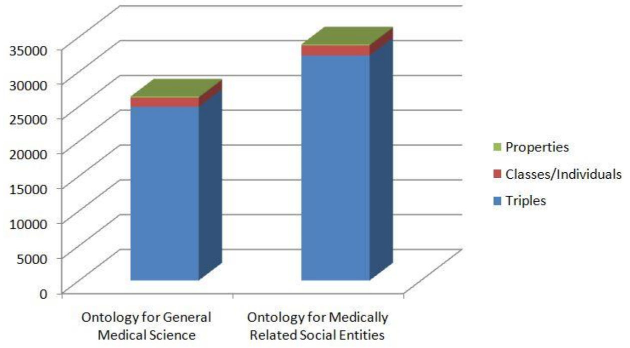


Fig. 8: Summarized result of medicine ontologies

Table 10: Result of medicine ontologies

Ontology Title	Triples	Classes/ Individuals	Properties	Total
NMR	7955	607	45	8607
MEC	37356	1538	179	39073

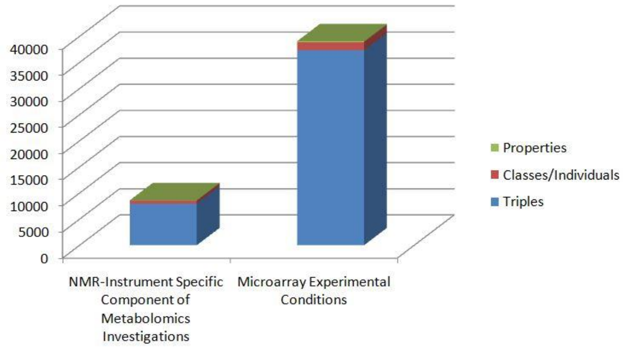


Fig. 9: Summarized result of experimental ontologies

Table 11: Result of experimental ontologies

Ontology Title	Triples	Classes/ Individuals	Properties	Total
SO	70134	3978	86	74198
OBCS	41167	2315	70	43552

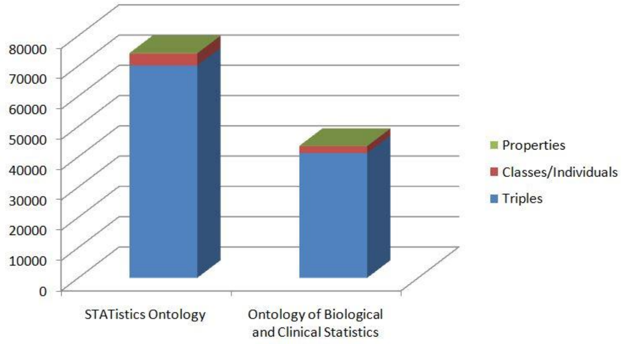


Fig. 10: Summarized result of statistics ontologies

As discussed earlier, the summarized result of biomedical ontologies related to Anatomy domain is shown in Table 8 and results are summarized in Fig. 6. The result of neuroscience ontologies is shown in Table 9 and Fig. 7. The result of medicine ontologies is shown in Fig. 8 and Table 10. The result of experimental ontologies is shown in Fig. 9 and Table 11. Fig. 10 represents the results of statistics ontologies. From the Table 8 and Fig. 6 it can be stated that Uber Anatomy Ontology possesses the highest coverage of structural components among the candidate Anatomy Ontologies. From Table 9 and Fig. 7 it is stated that NIF Cell Ontology possess the highest coverage of structural components between the candidate neuroscience ontologies. From the Table 10 and Fig. 8 it is stated that Ontology for medically related social entities possess the highest coverage of structural components among the candidate medicine ontologies. From Table 11 and Fig. 9, it stated that micro-array experimental conditions possess the highest coverage of structural components between the candidate experimental ontologies. From Fig. 10 it is stated that STATistics ontology possess the highest coverage of structural components between the candidate statistics ontologies. Similarly Chemical Entities of Biological Interest ontology possesses the highest coverage of structural components between the candidate chemical ontologies. Between mentioned two cell ontologies Cell Line Ontology has the highest coverage of structural components. As concerned to drug ontologies Drug Ontology possesses the highest coverage of structural components. Between mentioned two gene ontologies The Ontology of Genes and Genomes has the highest coverage of structural components. Similarly Physico-chemical methods and properties ontology possesses the highest coverage of structural components between the candidate physico-chemical ontologies. Lastly Ontology for MIRNA Target possesses the highest coverage of structural components between the candidate RNA ontologies.

V. Conclusion, Limitations and Future Directions

Ontologies are recognized as a valuable mean of representing the domain knowledge and become the core component of semantic web. The ontologies which have been developed till now require to be evaluated against certain criteria to ensure their quality and appropriateness about domain representation.

The need of ontology evaluation is highly necessary as users of ontologies are facing problems in selecting the appropriate ontology, which satisfies their requirement, among different sets of ontologies. The other factor that makes ontology evaluation a crucial task is the reuse in different applications and further development. Being a mode of sharing and representing domain knowledge, there must be an approach which can evaluate structural composition of ontologies. To accomplish this requirement, in our proposed methodology, structural or compositional quality evaluation of biomedical ontologies is carried out. The biomedical ontology with higher population density of each structural building block is advocated as high communicator of domain concepts.

The criteria which we used comprises of triples, classes, individuals and properties. The biomedical ontologies which are selected are in .owl form written in Ontology Web Language (OWL). These ontologies are imported in Protégé, that is one of the ontology building and ontology editing tool. For the extraction of results SPARQL Protocol and RDF Query Language (SPARQL) queries are applied on each biomedical ontology. The results of experiments are shown in both detailed and summarized form. Only distinct values of all structural components are considered and discussed in detail.

After describing detailed results in both tabular and graphical way, ontologies from same domain are compared with each other to get the appropriate and relative best ontology by summing up all classes, triples and properties to calculate total structural coverage of specific ontology and suggest the best one on structural basis. Experiments depict comprehensive and understandable results among many ontologies that which one is most appropriate and best with respect to structural components. One major limitation of our work is that only OWL-based ontologies are selected for experiments without considering other domains.

Furthermore the criteria can be applied in domains other than biomedical. It is obvious that the proposed work is based on structural constructs and can be further integrated with other metrics based on both qualitative and quantitative criteria. An integration of other evaluation techniques with our approach can provide a comprehensive methodology of evaluation of ontologies for biomedical applications. The proposed research can be utilized for selection of appropriate ontology, building bio-medical applications, information extraction, knowledge management, web intelligence systems and clinical decision support system. The integration of the proposed research with other existing evaluation criteria is a possible future direction of research.

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REFERENCES

[1] M. Amith, Z. He, J. Bian, J. A. Lossio-Ventura, and C. Tao, "Assessing the practice of biomedical ontology evaluation: Gaps and opportunities," *Journal of biomedical informatics,* vol. 80, pp. 1-13, 2018.

[2] K. R. Larsen, S. Michie, E. B. Hekler, B. Gibson, D. Spruijt-Metz, D. Ahern, *et al.*, "Behavior change interventions: the potential of ontologies for advancing science and practice," *Journal of behavioral medicine,* vol. 40, pp. 6-22, 2017.

[3] G. Bilgin, I. Dikmen, and M. T. Birgonul, "Ontology evaluation: An example of delay analysis," *Procedia Engineering,* vol. 85, pp. 61-68, 2014.

[4] A. K. Pujitha and J. Sivaswamy, "Solution to overcome the sparsity issue of annotated data in medical domain," *CAAI Transactions on Intelligence Technology,* vol. 3, pp. 153-160, 2018.

[5] O. Corcho, M. Fernández-López, and A. Gómez-Pérez, "Methodologies, tools and languages for building ontologies. Where is their meeting point?," *Data & knowledge engineering,* vol. 46, pp. 41-64, 2003.

[6] S. Khan, U. Qamar, and A. W. Muzaffar, "A framework for evaluation of owl biomedical ontologies based on properties coverage," in *2015 13th International Conference on Frontiers of Information Technology (FIT)*, 2015, pp. 59-64.

[7] A. Gangemi, C. Catenacci, M. Ciaramita, and J. Lehmann, "A theoretical framework for ontology evaluation and validation," in *SWAP*, 2005, p. 16.

[8] T. J. Bright, E. Y. Furuya, G. J. Kuperman, J. J. Cimino, and S. Bakken, "Development and evaluation of an ontology for guiding appropriate antibiotic prescribing," *Journal of biomedical informatics,* vol. 45, pp. 120-128, 2012.

[9] B. Sabir, U. Qamar, and A. W. Muzzafar, "Ontology development and evaluation for urinal tract infection," in *2014 IEEE Symposium on Computational Intelligence in Biometrics and Identity Management (CIBIM)*, 2014, pp. 195-201.

[10] M. R. Kamdar, T. Tudorache, and M. A. Musen, "A systematic analysis of term reuse and term overlap across biomedical ontologies," *Semantic web,* vol. 8, pp. 853-871, 2017.

[11] H. Zhao, P. Bai, Y. Peng, and R. Xu, "Efficient key management scheme for health blockchain," *CAAI Transactions on Intelligence Technology,* vol. 3, pp. 114-118, 2018.

[12] H. Hlomani and D. Stacey, "Approaches, methods, metrics, measures, and subjectivity in ontology evaluation: A survey," *Semantic Web Journal,* vol. 1, pp. 1-11, 2014.

[13] M. Gilbert and D. Williams, "A systems approach to user evaluation of biomedical ontologies," in *2008 First International*

Workshop on Ontologies in Interactive Systems, 2008, pp. 97-102.

[14] T. J. Callahan, I. J. Tripodi, H. Pielke-Lombardo, and L. E. Hunter, "Knowledge-Based Biomedical Data Science," *Annual Review of Biomedical Data Science*, vol. 3, 2020.

[15] K. Dramé, G. Diallo, F. Delva, J. F. Dartigues, E. Mouillet, R. Salamon, *et al.*, "Reuse of termino-ontological resources and text corpora for building a multilingual domain ontology: an application to Alzheimer’s disease," *Journal of biomedical informatics*, vol. 48, pp. 171-182, 2014.

[16] Y. Lin and Y. He, "The ontology of genetic susceptibility factors (OGSF) and its application in modeling genetic susceptibility to vaccine adverse events," *Journal of biomedical semantics*, vol. 5, pp. 1-15, 2014.

[17] M. Samwald, J. A. M. Giménez, R. D. Boyce, R. R. Freimuth, K.-P. Adlassnig, and M. Dumontier, "Pharmacogenomic knowledge representation, reasoning and genome-based clinical decision support based on OWL 2 DL ontologies," *BMC medical informatics and decision making*, vol. 15, pp. 1-10, 2015.

[18] J. Pratt, V. Pandian, E. Morrison, and A. A. Miller, "Developing a tool for crowd-sourcing to Verify a Radiation Oncology Ontology: a Summer Project," *Journal of Radiation Oncology Informatics*, vol. 6, pp. 42-52, 2017.

[19] P. Panov, L. Soldatova, and S. Džeroski, "Ontology of core data mining entities," *Data Mining and Knowledge Discovery*, vol. 28, pp. 1222-1265, 2014.

[20] A. T. McCray, P. Trevvett, and H. R. Frost, "Modeling the autism spectrum disorder phenotype," *Neuroinformatics*, vol. 12, pp. 291-305, 2014.

[21] A. Malhotra, E. Younesi, M. Gündel, B. Müller, M. T. Heneka, and M. Hofmann-Apitius, "ADO: A disease ontology representing the domain knowledge specific to Alzheimer's disease," *Alzheimer's & dementia*, vol. 10, pp. 238-246, 2014.

[22] M. Gündel, E. Younesi, A. Malhotra, J. Wang, H. Li, B. Zhang, *et al.*, "HuPSON: the human physiology simulation ontology," *Journal of biomedical semantics*, vol. 4, pp. 1-9, 2013.

[23] J. Van Soest, T. Lustberg, D. Grittner, M. S. Marshall, L. Persoon, B. Nijsten, *et al.*, "Towards a semantic PACS: using semantic web technology to represent imaging data," *Studies in health technology and informatics*, vol. 205, p. 166, 2014.

[24] S. De Coronado, M. W. Haber, N. Sioutos, M. S. Tuttle, and L. W. Wright, "NCI Thesaurus: using science-based terminology to integrate cancer research results," in *Medinfo*, 2004, pp. 33-37.

[25] G. O. Consortium, "The Gene Ontology (GO) database and informatics resource," *Nucleic acids research*, vol. 32, pp. D258-D261, 2004.

[26] P. L. Whetzel, R. R. Brinkman, H. C. Causton, L. Fan, D. Field, J. Fostel, *et al.*, "Development of FuGO: an ontology for functional genomics investigations," *OMICS: A journal of integrative biology*, vol. 10, pp. 199-204, 2006.

[27] C. Brewster, H. Alani, S. Dasmahapatra, and Y. Wilks, "Data driven ontology evaluation," 2004.

[28] G.-W. Kim and D.-H. Lee, "Intelligent health diagnosis technique exploiting automatic ontology generation and Web-based personal health record services," *IEEE Access*, vol. 7, pp. 9419-9444, 2019.

[29] S. Acharya, S. Saha, and P. Pradhan, "Multi-factored gene-gene proximity measures exploiting biological knowledge extracted from Gene Ontology: application in gene clustering," *IEEE/ACM transactions on computational biology and bioinformatics*, 2018.

[30] H. Abbes and F. Gargouri, "Structure based modular ontologies composition," in *2016 IEEE/ACS 13th International Conference of Computer Systems and Applications (AICCSA)*, 2016, pp. 1-8.

[31] X. Binfeng, L. Xiaogang, P. Chenglin, and H. Qian, "Based on ontology: Construction and application of medical knowledge base," in *2007 IEEE/ICME International Conference on Complex Medical Engineering*, 2007, pp. 1586-1589.

[32] Z. Huang, K. Lei, D. He, Y. Xu, J. Williams, L. Hu, *et al.*, "Self-regulation in chemical and bio-engineering materials for intelligent

systems," *CAAI Transactions on Intelligence Technology*, vol. 3, pp. 40-48, 2018.

[33] S. Tartir, I. B. Arpinar, and A. P. Sheth, "Ontological evaluation and validation," in *Theory and applications of ontology: Computer applications*, ed: Springer, 2010, pp. 115-130.

[34] P. Buitelaar, T. Eigner, and T. Declerck, "OntoSelect: A dynamic ontology library with support for ontology selection," in *In Proceedings of the Demo Session at the International Semantic Web Conference*, 2004.

[35] K. Supekar, C. Patel, and Y. Lee, "Characterizing Quality of Knowledge on Semantic Web," in *FLAIRS conference*, 2004, pp. 472-478.

[36] A. Lozano-Tello and A. Gómez-Pérez, "Ontometric: A method to choose the appropriate ontology," *Journal of Database Management (JDM)*, vol. 15, pp. 1-18, 2004.

[37] H. Alani, C. Brewster, and N. Shadbolt, "Ranking ontologies with AKTiveRank," in *International Semantic Web Conference*, 2006, pp. 1-15.

[38] Ó. Corcho, A. Gómez-Pérez, R. González-Cabero, and M. C. Suárez-Figueroa, "ODEval: a tool for evaluating RDF (S), DAML+ OIL, and OWL concept taxonomies," in *IFIP International Conference on Artificial Intelligence Applications and Innovations*, 2004, pp. 369-382.

[39] C. Welty and N. Guarino, "An Overview of OntoClean," *The Handbook of Ontologies. Springer Verlag*, 2003.

[40] L. Obrst, W. Ceusters, I. Mani, S. Ray, and B. Smith, "The evaluation of ontologies," in *Semantic web*, ed: Springer, 2007, pp. 139-158.

[41] A. Gangemi, C. Catenacci, M. Ciaramita, and J. Lehmann, "Modelling ontology evaluation and validation," in *European Semantic Web Conference*, 2006, pp. 140-154.

[42] L. Ding, R. Pan, T. Finin, A. Joshi, Y. Peng, and P. Kolari, "Finding and ranking knowledge on the semantic web," in *International Semantic Web Conference*, 2005, pp. 156-170.

[43] P. Haase, F. Van Harmelen, Z. Huang, H. Stuckenschmidt, and Y. Sure, "A framework for handling inconsistency in changing ontologies," in *International semantic web conference*, 2005, pp. 353-367.

[44] J. T. Fernandez-Breis, M. E. Aranguren, and R. Stevens, "A quality evaluation framework for bio-ontologies," *Nature Precedings*, pp. 1-1, 2009.

[45] A. B. Bouiadjra and S.-M. Benslimane, "FOEval: Full ontology evaluation," in *2011 7th International Conference on Natural Language Processing and Knowledge Engineering*, 2011, pp. 464-468.

[46] C. Ochs, Y. Perl, J. Geller, M. Haendel, M. Brush, S. Arabandi, *et al.*, "Summarizing and visualizing structural changes during the evolution of biomedical ontologies using a Diff Abstraction Network," *Journal of biomedical informatics*, vol. 56, pp. 127-144, 2015.

[47] V. V. Cross and A. Pal, "OntoCAT: An Ontology Consumer Analysis Tool and Its Use on Product Services Categorization Standards," in *SEBIZ*, 2006.

[48] M. Amith, F. Manion, C. Liang, M. Harris, D. Wang, Y. He, *et al.*, "Architecture and usability of OntoKeeper, an ontology evaluation tool," *BMC medical informatics and decision making*, vol. 19, p. 152, 2019.

[49] K. Meng, C. Cui, and H. Li, "An Ontology Framework for Pile Integrity Evaluation Based on Analytical Methodology," *IEEE Access*, vol. 8, pp. 72158-72168, 2020.

[50] D. Vrandečić, "Ontology evaluation," in *Handbook on ontologies*, ed: Springer, 2009, pp. 293-313.

[51] M. Quesada-Martínez, J. T. Fernández-Breis, and D. Karlsson, "Suggesting Missing Relations in Biomedical Ontologies Based on Lexical Regularities," in *MIE*, 2016, pp. 384-388.

[52] A. A. Alsanad, A. Chikh, and A. Mirza, "A domain ontology for software requirements change management in global software development environment," *IEEE Access*, vol. 7, pp. 49352-49361, 2019.

[53] J. H. Brenas, E. K. Shin, and A. Shaban-Nejad, "Adverse childhood experiences ontology for mental health surveillance, research, and evaluation: advanced knowledge representation and semantic web

techniques," *JMIR mental health*, vol. 6, p. e13498, 2019.

[54] C. Ochs, Z. He, L. Zheng, J. Geller, Y. Perl, G. Hripcsak, *et al.*, "Utilizing a structural meta-ontology for family-based quality assurance of the BioPortal ontologies," *Journal of biomedical informatics*, vol. 61, pp. 63-76, 2016.

[55] L. Cui, S. Tao, and G.-Q. Zhang, "Biomedical ontology quality assurance using a big data approach," *ACM Transactions on Knowledge Discovery from Data (TKDD)*, vol. 10, pp. 1-28, 2016.

[56] L. Cui, W. Zhu, S. Tao, J. T. Case, O. Bodenreider, and G.-Q. Zhang, "Mining non-lattice subgraphs for detecting missing hierarchical relations and concepts in SNOMED CT," *Journal of the American Medical Informatics Association*, vol. 24, pp. 788-798, 2017.

[57] D. L. Rubin, S. E. Lewis, C. J. Mungall, S. Misra, M. Westerfield, M. Ashburner, *et al.*, "National center for biomedical ontology: advancing biomedicine through structured organization of scientific knowledge," *Omics: a journal of integrative biology*, vol. 10, pp. 185-198, 2006.

[58] O. Bodenreider, "Identifying Missing Hierarchical Relations in SNOMED CT from Logical Definitions Based on the Lexical Features of Concept Names," *ICBO/BioCreative*, vol. 2016, 2016.

[59] Z. Wei, C. Licong, and Z. Guo-Qiang, "Spark-mca: Large-scale, exhaustive formal concept analysis for evaluating the semantic completeness of snomed ct," in *AMIA Annual Symposium Proceedings*, 2017, p. 1931.

[60] Y. Netzer, D. Gabay, M. Adler, Y. Goldberg, and M. Elhadad, "Ontology evaluation through text classification," in *Advances in Web and Network Technologies, and Information Management*, ed: Springer, 2009, pp. 210-221.

[61] C. Ochs, J. Geller, Y. Perl, and M. A. Musen, "A unified software framework for deriving, visualizing, and exploring abstraction networks for ontologies," *Journal of biomedical informatics*, vol. 62, pp. 90-105, 2016.

[62] Available: https://bioportal.bioontology.org/

[63] Available: http://www.obofoundry.org/

[64] D. L. Rubin, H. Knublauch, R. W. Fergerson, O. Dameron, and M. A. Musen, "Protege-owl: Creating ontology-driven reasoning applications with the web ontology language," in *AMIA Annual Symposium Proceedings*, 2005, p. 1179.

[65] H. Alani and C. Brewster, "Ontology ranking based on the analysis of concept structures," in *Proceedings of the 3rd international conference on Knowledge capture*, 2005, pp. 51-58.

[66] B. Smith, W. Ceusters, B. Klagges, J. Köhler, A. Kumar, J. Lomax, *et al.*, "Relations in biomedical ontologies," *Genome biology*, vol. 6, p. R46, 2005.

[67] R. Hoehndorf, P. N. Schofield, and G. V. Gkoutos, "The role of ontologies in biological and biomedical research: a functional perspective," *Briefings in bioinformatics*, vol. 16, pp. 1069-1080, 2015.

[68] M. Horridge, S. Jupp, G. Moulton, A. Rector, R. Stevens, and C. Wroe, "A practical guide to building owl ontologies using protégé 4 and co-ode tools edition1. 2," *The university of Manchester*, vol. 107, 2009.