Quality Framework for Ontology Evaluation Based on Structural Characteristics

Author

Reda Ayesha Khan

Regn Number

00000206709

Supervisor

Dr. Usman Qamar

DEPARTMENT OF COMPUTER AND SOFTWARE ENGINEERING

COLLEGE OF ELECTRICAL & MECHANICAL ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY

ISLAMABAD

February, 2020

Quality Framework for Ontology Evaluation Based on Structural Characteristics

Author

Reda Ayesha Khan

Regn Number

00000206709

A thesis submitted in partial fulfillment of the requirements for the degree of

MS Software Engineering

Thesis Supervisor:

Dr. Usman Qamar

Thesis Supervisor's Signature:____

DEPARTMENT OF COMPUTER AND SOFTWARE ENGINEERING

COLLEGE OF ELECTRICAL & MECHANICAL ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY, ISLAMABAD

February, 2020

Declaration

I certify that this research work titled "*Quality framework for ontology evaluation based on structural characteristics*" is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

Signature of Student
Reda Ayesha Khan
2017-NUST-Ms-Software-00000206709

Language Correctness Certificate

This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical and spelling mistakes. Thesis is also according to the format given by the university.

Signature of Student

Reda Ayesha Khan

Registration Number

00000206709

Dr. Usman Qamar

Signature of Supervisor

Acknowledgements

I am thankful to my Creator Allah Subhana-Watala to have guided me throughout this work at every step and for every new thought which You setup in my mind to improve it. Indeed I could have done nothing without Your priceless help and guidance. Whosoever helped me throughout the course of my thesis, whether my parents or any other individual was Your will, so indeed none be worthy of praise but You.

I am profusely thankful to my beloved parents who raised me when I was not capable of walking and continued to support me throughout in every department of my life.

I would also like to express special thanks to my supervisor Dr. Usman Qamar for his help throughout my thesis and also for data engineering and web engineering courses which he has taught me. I can safely say that I haven't learned any other engineering subject in such depth than the ones which he has taught.

I would also like to thank Dr. Wasi Haider and Dr. Muhammad Abbas my GEC committee for their support and cooperation

Finally, I would like to express my gratitude to all the individuals who have rendered valuable assistance to my study.

Dedicated to my exceptional parents and adored siblings whose tremendous support and cooperation led me to this wonderful accomplishment

Abstract

In the domain of semantic web, ontologies play an important role for extracting the information and knowledge about the specific domain and present the problem in more understandable form. There many ontological web portals and thousands of ontologies was made on different domains. So to find out which ontology is better and which ontology can solve the required problems. For this purpose, ontology evaluation is very important. The main focus of ontology evaluation is to estimating the quality of ontology. There many frameworks for evaluation but there is still problem to evaluate the ontologies. And evaluation method also used to estimate the quality of existing ontologies and finding the gaps in the ontology to improve the existing ontology. In this paper we proposed an evaluation technique that use the structure characteristics to examine the quality of ontologies. For this we select different domains ontology and apply the proposed evaluation criteria. In our evaluation criteria, we check the quality of ontology on the basis of structured characteristics. Also our proposed framework can compare the same domain ontologies and tells which is best in terms of quality. The proposed framework can also evaluate all different formats of ontologies but the queries are different for different format. In this research we only apply owl format queries. But for the different formats of ontology the evaluation criteria are same only he queries are different according to the format.

Key Words: *Ontology, Structural characteristics, Quality, SPARQL , Ontology evaluation, Semantic web*

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

CHAPTER 1: INTRODUCTION

In this research work we have evaluated the ontologies by defining a quality framework and discuss the results of the evaluation. The proposed criteria also used to compare the different ontologies of the same domain and describe which ontology is best according to the quality.

1.1 Background

For the transformation of data into the meaningful or understandable format the significant evaluation on web is semantic web [1]. After the better understanding of data, this transformation helps to link and processed the data through multiple sources. Ontologies can provide information as semantically because of this ontology are used as the representation of knowledge. In the last decades, ontology is significantly used and called "The Backbone technology in the most knowledge based Applications" [2]. A detailed definition of ontology is following [1].

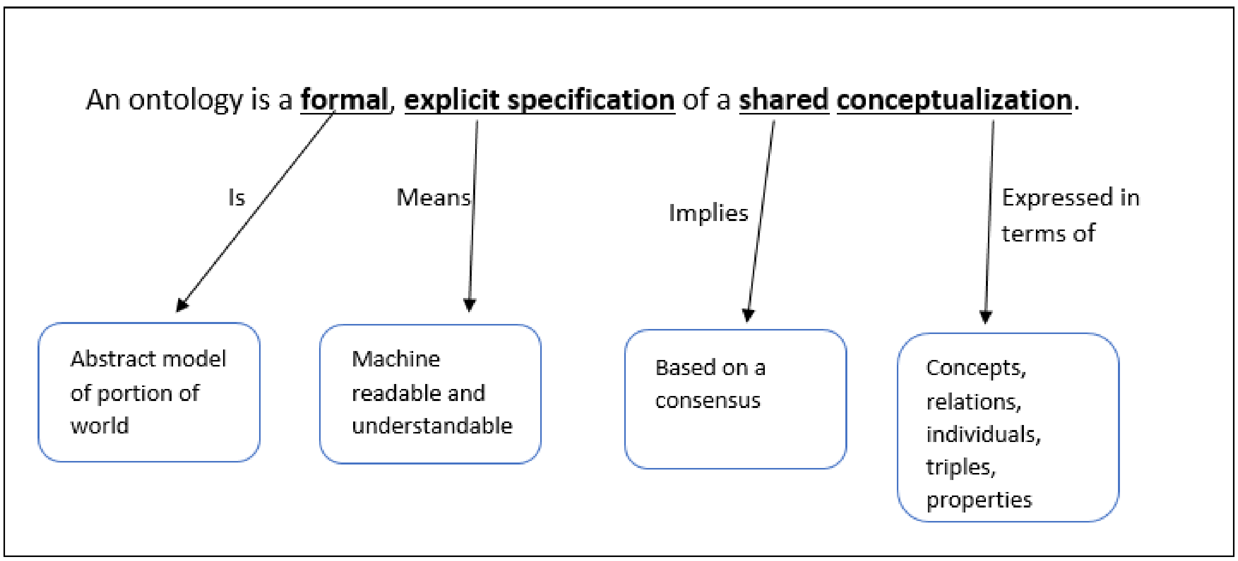


Figure 1.1-1 Definition of Ontology

Ontologies now used in many fields but it is the core of semantic web. Reasons to make ontology [3,4].

- To share basic comprehension of the structure of data among individuals or programming operators
- To empower reuse of area learning

- To make area suppositions unequivocal
- To isolate domain information from the operational learning
- To dissect area learning

Sharing regular comprehension of the structure of data among individuals or programming specialists is one of the more shared objectives in creating ontologies. For instance, [1] assume a few distinctive Websites contain restorative data or give ecommerce service for medical. On the off chance that these Websites share and distribute the equivalent basic cosmology of the terms they all utilization, at that point PC operators can concentrate and total data from these various sites [5]. The operators can utilize this collected data to answer client questions or as input information to different applications.

1.1.1 Structure of ontology:

The functions of ontology can be rationalized by its structure. Basically ontologies are used for the communication of machine to human or intermachine communication [6]. Ontologies are the hierarchal relationship for the illustration of class/concept in the specific domain. Ontology can represent the data into different parts; concept/class, individual, triples (subject, object, predicate), Relations, properties [1,2,7].

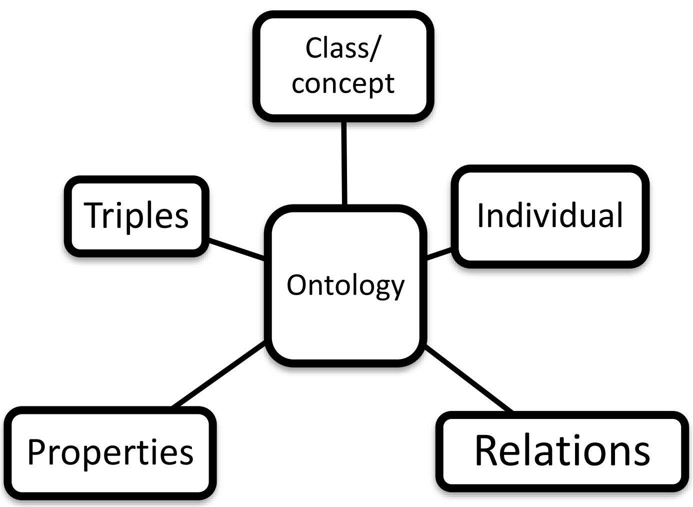


Figure 1.1-2 Structure of ontology

These five are the structural components of a simple ontology. These components are very important, because everyone has its different meaning and use in the formation of ontology [8]. These are explained in methodology in detail.

1.1.2 Applications and Bio-medical Ontologies

Ontologies are very first utlized in the field of healthcare and life science(HCLS). A few projects in social insurance have been started at government level to give better human services benefits by empowering data interoperability crosswise over geological limits [9].

A portion of the real attributes of ontologies are that they guarantee a typical comprehension of data and that they make unequivocal domain presumptions. Subsequently, the interrelation and interoperability of the model make it significant for tending to the difficulties of getting to and questioning information in organization [10]. Additionally, by improving metadata and provenance, and consequently enabling organization to understand their information, ontologies upgrade information quality.

In a semantic and syntactic level ontologies are the fundamental component of EHealth activities [1] to deliver information. The traditional systems of terminology are esteemed to be deficient as for the necessities of social insurance data frameworks that rely upon clear correspondence of complex medical and biological data in a structure that is usable by PCs [11]. The selection of an ontological methodology for overseeing biomedical terminology encourages a portion of the undertakings related with these exercises [12], as laborers in both clinical and biological areas have found.

Ontologies are used for sharing data into different decision support systems for example mostly in clinical decision support systems (CDSS) [13].

1.1.3 Evaluation of ontology and its importance:

Ontology evaluation plays a very significant part. The main focus of ontology evaluation is to estimating the quality of ontology [14].

Evaluation of ontology can be done mostly for two main reasons. First to measuring the correctness or quality of ontology (after the ontology is developed) and second for the comparison with the other ontologies (this is done before and after the development of ontology

[15]. Before development of ontology, the evaluation is done to estimate the quality of existing ontologies and finding the gaps in the ontology to improve the existing ontology. After development of ontology, evaluation is done for the examine the quality of the ontology) [1].

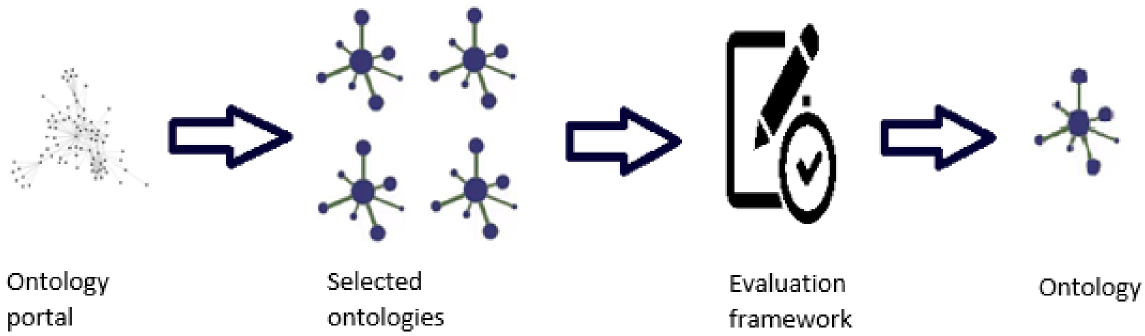


Figure 1.1-3 Formation of ontologies

There are many ways to evaluate the ontologies for example some evaluation frameworks can examine the completeness and consistency (formal properties), some examine the quality and coverage of the ontologies and some check the issues relates to the usability and coverage [3]. Some examine the accuracy, clarity and computational efficiency. And for the evaluation purpose there are many frameworks are introduced.

1.2 Problem Statement

There are many ontology web portals and thousands of ontologies was made on different domains. So to find out which ontology is better and which ontology can solve the required problems. For this purpose, ontology evaluation is very important. The main focus of ontology evaluation is to estimating the quality of ontology [14]. There many frameworks for evaluation but there is still problem to evaluate the ontologies. And evaluation method also used to estimate the quality of existing ontologies and finding the gaps in the ontology to improve the existing ontology.

1.3 Scope and Objective

Ontologies are used in many different fields for example information extraction, bio medical, Clinical Decision support systems, data integration and semantic web. This study evaluates the existing ontologies to check their quality and check that they are fit to use. The objective of this study is to develop a framework that evaluate different domains ontologies according to their structural characteristics and examine the quality of ontologies. And compare the same domain ontologies to examine which is the best in terms of quality and structure.

1.4 Motivation

Due to various work is done on the formation of ontologies and their usage in different fields and domains [5]. There is a need for the evaluation of the ontologies to examine the quality of ontology. There are many frameworks or methodologies proposed for the evaluation of ontology but they can't fully examine the quality matrices or cover all the structural characteristics and evaluate different formats of ontologies [7]. Many ontologies are made on different domains and there are many portals where the ontologies are available the users can't decide which can fulfill the required need for this purpose the evaluation is used to compare the same domain ontologies and find the best one according to the quality and fitness for use [1].

In the 2nd chapter the existing frameworks are explained in details with their drawbacks and coverage. In the 3rd chapter the proposed methodology in explained and also the structural characteristics are explained which are used for the evaluation. In the 4th chapter the results and explained in details along with the graphs.

Chapter 2

Literature Review

CHAPTER 2: LITERATURE REVIEW

Ontology evaluation is the most important and complex part of ontology engineering [5] process because it involves in the different levels of ontology formation that are evaluation and the reuse. There are a rich number of techniques and metrics for the evaluation of ontologies. In this chapter we defined and explain the methods, framework and approaches of ontology evaluation and their quality coverage.

Gomez Perez proposed in 1945 the idea for the evaluation of ontologies and define a set of properties for evaluation purpose. Structure of ontology, its context and syntax was examining. These properties can solve the problems related to consistency, conciseness and completeness.

2.1 Gold Standard

In golden standard the consistency and coverage of domain is validate the efficiency of ontology. In this technique we compare the ideal ontology and resultant/ learning ontology [16]. In the ideal ontology the standard and benchmark is predefined. Domain experts manually make the ideal ontology that is used for comparison [17]. This technique works really well for the large scale and for the frequent evaluation. It involves multilevel evaluation that is semantic level, lexical and taxonomic level. The shortcomings of this techniques are its generally depends on the relative measures and hard to compare the ontologies for quality measure [17,18].

2.2 Application based Evaluation

Application based approach is also known as task based evaluation or task oriented. It evaluates the ontology by performing some task on the application. In this approach [19], numerous task has been performed on the ontology which is evaluated to examine its performance and it also enables to detect the inconsistency of concepts. Application-based evaluation [20] examines the accuracy, coverage and ontology in context to other applications. The shortcomings of this approach is that [21] (1) ontologies can't be compared if they have not the same embedded application and the same type and number of tasks performed [21]. (2) It's really hard to evaluate the ontology, if ontology was the small module of application so it has the less effect on the evaluation results [22]. (3) When used the ontology in a specific way to examine the task it's hard to simplify the observation either it's good or bad [19].

2.3 Data Driven Approach

Also known as "Corpus-based Evaluation", in this technique we use the existing source information to assess the coverage degree of the specific domain ontology [23]. The key advantage is that this approach facilitates the evaluation of one or more targeted ontologies with a particular domain. The challenge of this approach is to find the domain specific corpus [24]. This type of approach is used for the domain specific ontologies. Similar to the gold standard this approach also evaluates the completeness, consistency and validate the efficiency of ontology [21].

2.4 User-based Evaluation

User-based evaluation also known as "Human Evaluation". In this technique user select the best ontology from the several number of selected ontologies by performing some selected tasks [25]. According to the tasks ontologies get a numerical number and highest number ontology called the best one [21]. The tasks are based on the decision criteria of formulation. The shortcomings of this technique is that it is very costly in terms of effort and time and that's why this technique is not used now-a-days.

The above mentioned evaluation techniques are the traditional techniques for the evaluation of the quality of the ontologies.

2.5 Lexical Based Approaches

Luo [26] introduced an automatic computational approach that can compute the linguistic structure and bi-similarity of the ontologies in the concept names. This approach used two modifiers which are "left" and "right" According to the hierarchy the symmetric pairs are computed by the all possible structure pairs. This approach was then modified by Agrawal [27], he introduced the utilization of lexical method to find the inconsistency in the formal definition of SNOMED CT. in his approach he explains the five hypothesis which he used in the algorithm. These hypothesis was based on the lexical similarity sets i.e. "Similarity sets whose concepts exhibit different number of parents are more likely to harbor inconsistences than randomly selected similarity sets." [28,29] introduced the methods that identify the missing relations in lexical feature. [28] find the relations in successive tokens in a labels of ontologies. Identify the missing hierarchical relations in OWL concept name of lexical feature [29].

2.6 Popularity Based Approaches

Ontokhoj[30] used the algorithm which can firstly search the ontologies than aggregate them thirdly rank the ontologies and at the end classify them. Also Ontokhoj web portal can accelerate the procedure of ontology evaluation through wide reuse of ontologies. Swoogle [31] is the semantic web search engine for searching ontologies. This approach uses the "OntoRank" algorithm for evaluation of ontologies [30].

OntoSelect compare the results of evaluation with "Swoogle". This evaluation technique use Wikipedia pages that has the similar topic with the linked ontologies by introducing the benchmarks. As the comparison of both techniques the author [32] conclude that on average results swoogle is better approach than Ontoselect. These approaches were not precisely introduced for biomedical ontologies [33].

2.7 Matric based and other multi Criteria Evaluation

Matric based evaluation is based on the correctness and prioritizing the characters of the ontologies [48]. Matric assess the quality of ontology and to identify the attributes of ontology without any consistency. [47]

According to the system needs, OntoMetric [34] can allow the users to examine the correctness of the ontologies. This method's targeted audience was the users which are either project manager [36] or engineers who can search the ontologies on the web for their systems or applications. In 2019 Jean [35] use this approach for evaluation of E-government ontologies to find the gaps on the existing ones. And examine the accuracy cohesion and understandability purpose.

Vadiam [37] introduced the OntoElect approach for the evaluation and refinement of the fitness of ontologies. For evaluation this approach uses three phases. Onto Elect extracts the terms from the gathered documents than assign the numerical figure according to the information gained from the documents.

Xiaogang (2018) proposed a usability [38] scale for ontology evaluation. According to the framework, he uses the prepared statements that was derived from Likert scale. He also provides the online poll for ontology evaluation purpose. This approach is mostly based on the Brooke (1996) [39]. This approach also used for different types of domain ontologies for evaluation.

AKTiveRank [40] rank the ontology on the bases of “Class Match Measure (CMM)”. In this approach the author uses a structural metrics for ranking ontologies in a prototype system. This approach uses the analytic methods for rating purpose. Rate is assign to the ontology according to the performance estimation of the given search item and make a classification matric. Using this approach, it is difficult to find out the best method for the selection of structural properties or parameters when we rank the ontologies. Select of method for ranking is highly dependent to the user requirements.

ODEval [41] is used to find out the redundancy and inconsistency in the ontologies. The ontologies that are implemented in the formats of web semantics languages RDF, OWL and DAML+OIL this approach can evaluate them. This approach is mostly used by project designers for reuse the ontologies and for knowledge representation. This framework also helps to determine the identification of deficiency in ontologies. And also for this approach user requirement is very important for the evaluation of ontologies.

The Ontoclean [44] approach for ontology evaluation used to verify the ontology capability, effectiveness and the taxonomic relationships consistency. This approach permits the structure of clean ontologies. The work done on this methodology was highly dependent on the unity, dependency, essence, identity and rigidity notions [42]. This methodology has four layers [43] and the below layer is dependent on the higher layer. The nature of the properties that has been entangled in the relationships, this methodology helps the users to analyze them. This methodology does not focus on the structural resemblance between the properties.

OntoQA [45] methodology is used for the description of metrics of the ontologies that has been defined or implemented in RDF format. The metrics explain the classes and its instances and how the classes has been arranged in the schema. This model is mostly used for the definition of metrics. The metrics explain the class and sub class relationships and also the other kind of relations if found. The metrics is used to discover the important characteristics in the schema of ontology and also allow the users to make a very quick decision about the ontology. Tri [46] used OntoQA model to evaluate its framework and obtained the value of relations richness.

2.8 Evolution Based Evaluation

Ontology evolution is the variation of ontology in a constant way. [49,51] The ontology can evolve from one state to the other. The evaluation process is needed when the ontology can change the domain specification and the evolution process can also effect the dependent application. Some inconsistency problems may occur. The process of evolution has six phases [49] (1) Changes are captured. (2) Represent the changes. (3) Change semantics. (4) Propagation changes. (5) Implementation changes. (6) validation changes.

For this purpose, Rim [50] proposed a framework ONTO-EVOL for the evaluation of ontologies. In his framework a pattern oriented process (POP) is used. The purpose of the POP is to control the changes in the dependent application during the process of maintenance. The main activity of his framework is to reserve the quality of ontology. This process is also used for the change management and quality evaluation.

Renata [49] evaluate the evolve ontologies using S-ONTOEVOL tool to examine the quality of ontologies. Author evaluate the ontology on the bases of its structure, usability and fundamental evaluation.

2.9 Logical or Rule Based Evaluation

These methodologies are based on the rules that was defined by the users of the ontologies to identify the conflicts and inconsistences to improve the quality. [51] For example, the two classes are said to be different or two classes are said to be same or there is a constant number of instances. Some rules may be conflicts with each other that was describe by the users [52].

Serval frameworks adopted this type of methodology to evaluate the ontologies for example OntoLoki [52]. In this approach, rules are used for the instance properties to determine the relations. And they gave a quantitative score according to the fulfillment of the rule.

Another methodology which is using the rule based approach in Swoop [54]. In Swoop model a logical method is used to identify the inconsistency, redundant and fault concepts in OWL ontologies. This methodology is mostly used by the application designers to test or verify the quality of their work and to find out if there are other problems left which can affect the application later or the quality of the ontology is achieved.

2.10 Structure Based Evaluation

Many structure-based approaches are automated. This technique evaluates the ontologies by the different type of structural properties for example the classes and their relation density, depth and breadth the nodes and the graphical representation.

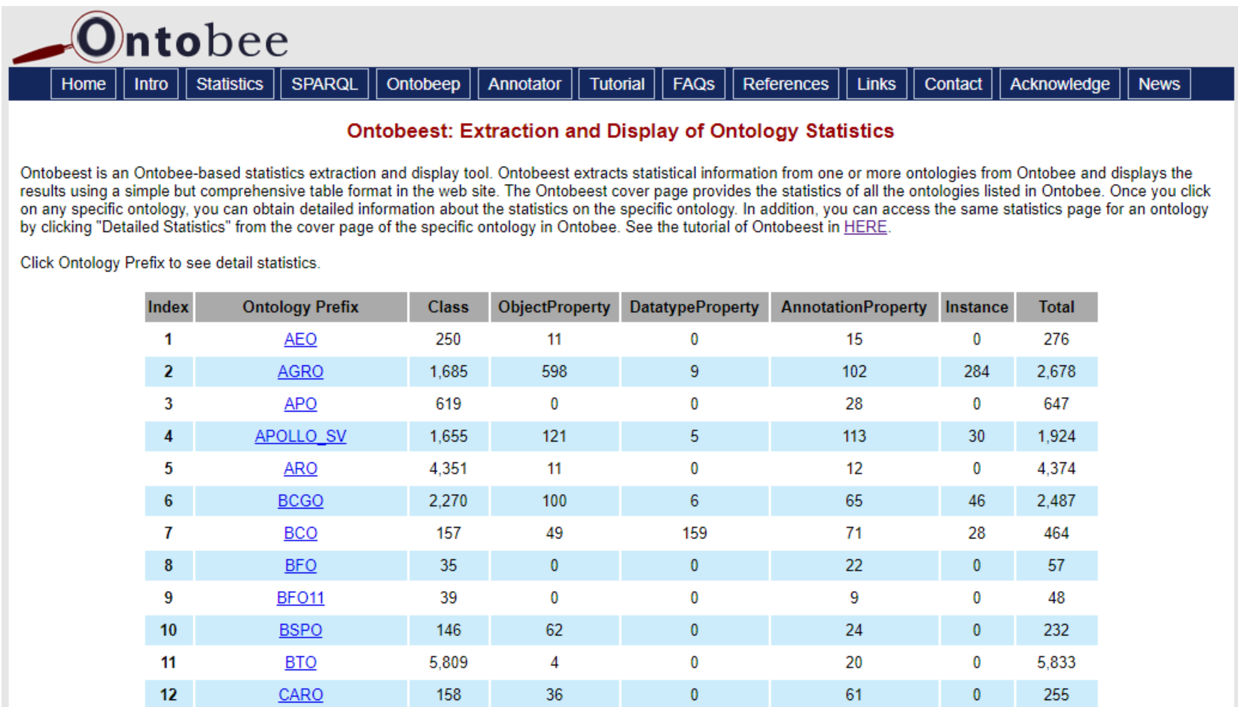
Gangemi [56] proposed a model in which he evaluate or validate the meta-theoretical foundation using the O^2 and oQual models. oQual helps to gathered the elements of ontology by the means of O^2. oQual based on the three types measurements [38], first is the structural measure than functional and usability measure. But while doing the structural measure the functions are very poorly defined and also the usability measure is less defined. oQual provides a way to context and ontology engineering. oQual includes the evaluation of ontology on the bases of the concepts (class), parameters and the value space of the elements of the ontologies [55].

Ning [58] proposed the methodology for the structural based evaluation of ontologies using the graph theory and explain the structure of ontology with six different type of properties. Ning methodology use the six properties to describe the structure of ontologies and evaluate the quality.

OntoQA [45] methodology is used for the description of metrics of the ontologies that has been defined or implemented in RDF format. The metrics explain the classes and its instances and how the classes has been arranged in the schema. This model is mostly used for the definition of metrics. The metrics explain the class and sub class relationships and also the other kind of relations if found. The metrics is used to discover the important characteristics in the schema of ontology and also allow the users to make a very quick decision about the ontology. Tri [46] used OntoQA model to evaluate its framework and obtained the value of relations richness. The OntoQA methodology evaluate the ontologies on the bases on the class (concept), the relations between the classes or concepts and the instances (individuals).

Khan proposed a framework [60] for the evaluation of ontologies using the SPARQL queries on ontologies. His framework evaluates the ontology on the bases of structural characteristics. The characteristics that includes in the framework was: classes, individuals, triples (Subject, Object, Predicates), and the properties. The drawback of the framework was that its only evaluates the .owl formats ontologies. And the framework can only evaluate the bio-medical ontologies and in the framework the important structural character of ontology is missing that is relations. The framework cannot evaluate the relations of the class and the relations between the class and individuals.

OntoBee [59] is linked with obo foundry. Obo foundry is a bio medical ontology portal. This bio portal support RDF/HTML formats of ontology. OntoBee proposed an evaluation criterion for ontologies. The statistics that are used for evaluation was the classes, instances, datatype property, object property and annotation property. OntoBee has an online web portal for evaluate the ontologies.


Ontobee

Home | Intro | Statistics | SPARQL | Ontobeep | Annotator | Tutorial | FAQs | References | Links | Contact | Acknowledge | News

Ontobeest: Extraction and Display of Ontology Statistics

Ontobeest is an Ontobee-based statistics extraction and display tool. Ontobeest extracts statistical information from one or more ontologies from Ontobee and displays the results using a simple but comprehensive table format in the web site. The Ontobeest cover page provides the statistics of all the ontologies listed in Ontobee. Once you click on any specific ontology, you can obtain detailed information about the statistics on the specific ontology. In addition, you can access the same statistics page for an ontology by clicking "Detailed Statistics" from the cover page of the specific ontology in Ontobee. See the tutorial of Ontobeest in HERE.

Click Ontology Prefix to see detail statistics.

Index	Ontology Prefix	Class	ObjectProperty	DatatypeProperty	AnnotationProperty	Instance	Total
1	AEO	250	11	0	15	0	276
2	AGRO	1,685	598	9	102	284	2,678
3	APO	619	0	0	28	0	647
4	APOLLO_SV	1,655	121	5	113	30	1,924
5	ARO	4,351	11	0	12	0	4,374
6	BCGO	2,270	100	6	65	46	2,487
7	BCO	157	49	159	71	28	464
8	BFO	35	0	0	22	0	57
9	BFO11	39	0	0	9	0	48
10	BSPO	146	62	0	24	0	232
11	BTO	5,809	4	0	20	0	5,833
12	CARO	158	36	0	61	0	255

Figure 2.10-1 OntoBee Statistics

Ming toa [57] create a relation database model for the evaluation of ontologies. He evaluates three different type of test files to examine the results of its model. He briefly explains the database model and the generated results to explain the evaluation of ontology on the bases of the structural characteristics. Author evaluate the ontologies on the bases of the following characteristics, class, instances and their relations and some instances properties. Ming’s relation-database model only evaluates the RDF format ontologies [57]. Other formats like .owl and .obo are not evaluated using this model.

The following table describe the various levels of ontology learning in the ontology evaluation frameworks. And show which framework evaluate which level. Different frameworks cover different levels there is no such framework which can cover all the levels of ontology learning. For full evaluation one can use two or three evaluation frameworks or can evaluate the ontology according to their requirements.

Table 2.10-1 levels of ontology and the frameworks

Framework	**Lexical, vocabulary, Concept**	**Semantic relation**	**Application**	**Syntax**	**Structure**	**Domain cohesion**	**Properties of classes**	**Usage statistic**	**Hierarchy**
Application-based evaluation	Yes	Yes	Yes	-	-	-	-	-	Yes
Gold Standard	Yes	Yes	-	Yes	-	-	-	-	Yes
Data driven	Yes	Yes	-	-	-	Yes	-	-	Yes
AKTive Rank	-	-	-	-	Yes	Yes	-	-	-
Ontoclean	Yes	Yes	-	-	Yes	-	-	-	-
Ontokhoj	-	-	-	-	-	Yes	-	Yes	-
Onto-Metrics	-	-	-	Yes	-	-	-	-	-
ODEval	Yes	-	-	-	-	-	-	-	-
Swoop	-	Yes	-	Yes	-		Yes	-	-
OntoQA	-	-	-	-	Yes	-	Yes	-	-
Onto-Select	-	-	-	-	Yes	-	-	-	-
ONTO-EVOL	-	-	-	Yes	Yes	Yes	-	Yes	-
Semiotic Metrics	-	-	-	Yes	-	Yes	-	Yes	-
Swoogle	-	-	-	-	-	-	-	Yes	-

2.11 Analysis

The following table explain the frameworks of ontology evaluation's objectives, coverage and how they can relate to the relate to this research.

Table 2.11-1 Existing Frameworks and their description

Sr #	Frameworks	Ref.	Year	Type of approach	Drawbacks	Related to this research
1	Gold Standard	[16,17,18]	2016	Traditional	• Based on the relevant comparison • Hard to compare quality measure • Can't evaluate the structure of ontologies.	• Evaluate the ontology • Examine the quality • Compare the ontology with the standard ontology.
2	Application Based	[19,20, 21,22]	2018	Traditional	• Can't evaluate if the ontology is not embedded with any system • Only evaluate the specific tasks • Can't evaluate the small ontologies • Can't evaluate	• Evaluate the ontologies using an application • Examine the consistency and quality

					all the structural characteristics of ontologies	
3	Data driven Approach	[21,23,24]	2011	Traditional	• Domain specific • Only evaluate or compare the same domain ontologies • Can't evaluate all the structural characteristics of ontologies	• Similar to the gold standard • Evaluate the ontology • Validation and quality comparison
4	OntoKhoj	[30,31]	2004	Popularity Based	• Can't evaluate the structure, semantic relation of the ontologies • It's only give information about the domain cohesion of the ontologies.	• Use for the evaluation of ontologies • Evaluate the existing ontology • Evaluate the quality
5	OntoSelect	[32]	2018	Popularity Based	• Can't compare the ontologies • Evaluate only the structure	• Evaluate ontology according to their

					• Results of evaluation are not so good as compare to the other techniques	structure and examine the quality
4	Onto-Matric	[34,35, 36]	2018	Matrices based approach	• Does not give information about the semantic relation of the ontologies. • Can't evaluate all the structural characteristics of ontologies.	• Evaluate the ontologies by create a matric • Find the gaps in the existing ontologies
5	OntoElect	[37]	2005	Matric based approach	• Does not tell much information about the structure of ontologies • Also don't give any information about the semantic relation and	• Evaluate the existing ontologies. • Give a quantitative number for the quality of ontologies

					domain knowledge • Can't evaluate all the structural characteristics of ontologies.	
6	AKTiveRank	[40]		Matric based approach	• Can't give much information about the ontologies • Can't evaluate all the structural characteristics of ontologies.	• Evaluate the quality of ontologies • Rank the otology according to the quality
7	ODEval	[41]	2018	Matric based approach	• Don't give the information about the hierarchy of semantic terms • Can't evaluate all the structural characteristics of ontologies.	• Evaluate the quality and reuse of the ontologies • Create a matric for evaluation • Evaluate the .owl format ontologies. • Evaluate according to the user

						requirements
8	OntoClean	[42,43, 44]	2015	Matric based approach	• Does not focus on the structural resemblance between the properties. • Can't evaluate all the structural characteristics	• Evaluate the ontologies • Evaluate the existing ontologies
9	OntoQA	[45,46]	2006	Matric based approach	• Can't evaluate all the structural characteristics . • And only evaluate the bio medical ontologies with .owl formats	• Evaluate the structure of ontology to examine the quality • Examine the semantic relation and the concepts and related properties
10	ONTO-EVOL	[50,51]	2015	Evolution based Approach	• Can't examine the classes and the properties and the semantic relations	• Evaluate the ontology quality after the evolution. • Compare the ontology
11	S-	[49]	2008	Evolution	• Only evaluate	• Evaluate the

	ONTOEVOL			based Approach	the fundamental aspects of ontology. • Can't evaluate all the structural characteristics of ontologies	structure according to the quality of ontologies.
12	OntoLoki	[52]	2015	Logical/ Rule base approach	• Only evaluate the instances and their relations according to the rules • Only evaluate the rules that are described by the user • Not all aspects are evaluated • Can't evaluate all the structural characteristics of ontologies	• Evaluate the ontology quality according to the users.
13	Swoop	[54]	2009	Logical/ Rule base approach	• Can't evaluate all the structural characteristics	• Evaluate the quality of ontology according to

					of ontologies. • Only evaluate the bio-medical ontology with the .owl formats. • Only evaluate according to the rules that are pre described.	the structural characteristics.
14	oQual	[38,55, 56]	2016	Structural based approach	• Only evaluate the bio-medical ontology with the obo formats. • Can't evaluate all the structural characteristics of ontologies. • Only evaluate the bio medical domain ontologies.	• Evaluate the ontology according to the concepts, value space and parameters.
15		[38,39]	2018	Matric based approach	• Can't describe	• Evaluate the

					the domain knowledge. • Can’t evaluate the structure or semantics of ontology.	ontology.
16		[58]	2006	Structure based approach	• Can’t evaluate all the structural characteristics of ontologies. • Only evaluate the properties. • Don’t give any domain knowledge and the semantic relations.	• Evaluate the ontology according to the properties and examine the quality.
17		[60]	2015	Structural based approach	• Can’t evaluate all the structural characteristics of ontologies. Relations between the concepts and instances are missing. • Only evaluate	• Evaluate the quality of ontologies according to the structural characteristics.

					the bio medical ontologies with the owl formats. • Can’t explain the comparison of ontologies.	
18	OntoBee	[59]	2011	Structural based approach	• Can’t evaluate all the structural characteristics of ontologies only evaluate the relations of concepts and the properties are evaluated. • Only evaluate the RDF formats ontologies.	• Evaluate the quality of ontologies according to the structural characteristics. • Explain the comparison of ontologies.
19		[57]	2017	Structural based approach	• Can’t evaluate all the structural characteristics of ontologies the triples (subject,	• Evaluate the quality of ontologies according to the structural characteristics and explain

					object and predicates) are missing.	the relation of concepts and instances. • Explain the comparison of ontologies
20		[26,27, 28]	2014	Lexical Based Approaches	• Can't compare the similar ontologies. • Can't evaluate all the structural characteristics of ontologies	• Evaluate the ontologies according to the relations between the concepts

Chapter 3

Proposed Methodology

CHAPTER 3: PROPOSED METHODLOGY

As discussed in the literature the previous ontology evaluation frameworks and their approaches for the evaluation purpose. And the objectives and the drawbacks of the existing frameworks are also discussed. To resolve the drawbacks of the existing frameworks, we proposed a methodology which can help to solve the existing methods drawbacks and evaluate the quality of ontologies. For this purpose, the proposed evaluation framework can evaluate the ontologies on the bases of all structural characteristics and evaluate all domains related ontologies using the SPARQL queries. The proposed framework also compares the ontologies which has the same domain and give information about which ontology has more characteristics and has the better quality. The structural characteristics that covered in the proposed framework are concepts, instances, relations between the classes and instances, triples (Subject, Object and Predicates), and almost all kind of properties ae covered.

3.1 Workflow

The proposed methodology framework has the following steps for the evaluation of ontologies. The steps are (1) Select the ontology form the portal or select your ontology (2) import the ontology into the protégé (3) apply the SPARQL queries one by one on each ontology (4) Gathered the results (5) compare the results for comparison of same domain ontologies. The flow graph of the framework is following:

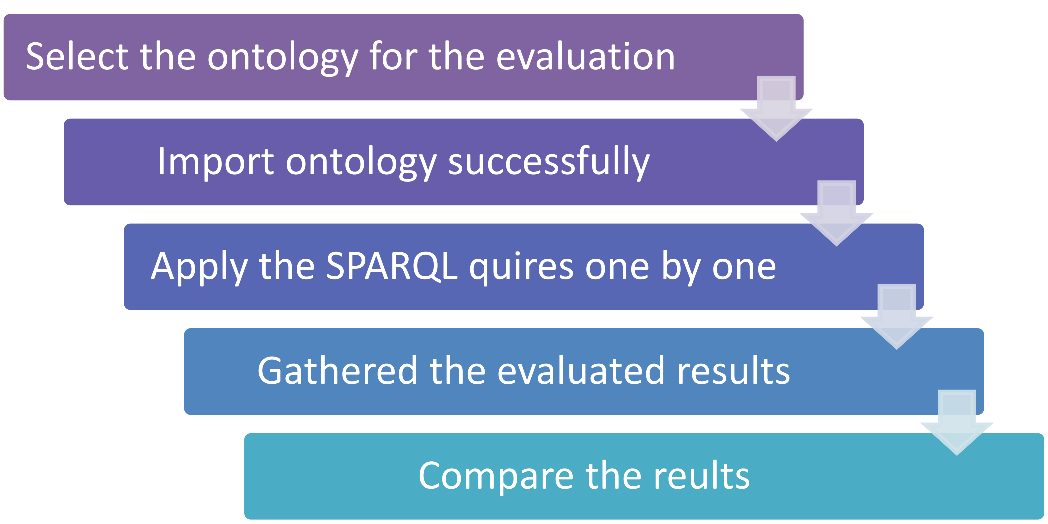


Figure 3.1-1 Workflow

The first step is to gathered the ontology from the portal in this framework ontology data is gathered from the NCBO or OBO foundry. About the data gathering we already discussed in the chapter 3 in detail about the portals and the selected ontologies. The domains of the evaluation which are selected for the framework are human anatomy (Bio-medical related domain), Animals ontologies (Animal related domain), Chemical ontologies (Chemical and physics related domains), Neurological disease ontologies (Medical related domain) and Plant ontology (Biological domain).

The second step is to import the ontologies into the protégé. Protégé is the software mostly used for the formation of ontologies in different formats like OWL, OBO and XML/RDF. Protégé support all formats of ontologies so for the evaluation this is the best tool. For the evaluation, this framework use owl and obo formats of ontologies. We select the owl and obo formats ontologies for the evaluation purpose.

The third step is to apply the SPARQL queries on the imported ontologies. SPARQL queries are applied on each ontology one by one to calculate the results against the queries. These queries are also used in the SQL database but in this framework we used these queries in the protégé. Because protégé is used for the making of ontologies so we used this for the evaluation purpose. SPARQL queries are easy to understand and easy to use.

The forth step is to gathered the results after applying the SPARQL queries. All the results of the queries are representing in the form of tables in the next chapter of the experimentation. The results also explain in the form of graph for the better understanding of the results. The results of the queries show the quality of the ontologies.

The fifth and the last step is used when we have to compare the two different ontologies of the same domain or same name to find out which can perform best in terms of quality and give the better results. For this purpose, the whole process is performed for both of the ontologies and then the computed results are representing in the form of tables or in the form of graph.

3.2 Evaluation Criteria:

The selected criteria for the evaluation of ontology is based on the structural characteristics. For the literature review, the following structural characteristics are selected of the proposed methodology. The characteristics are concepts which are the major block of the ontologies, instances or individuals, the relations between the concepts and the relations between the concepts and the instances, triples (Subject, Object, Predicates) and all the possible properties.

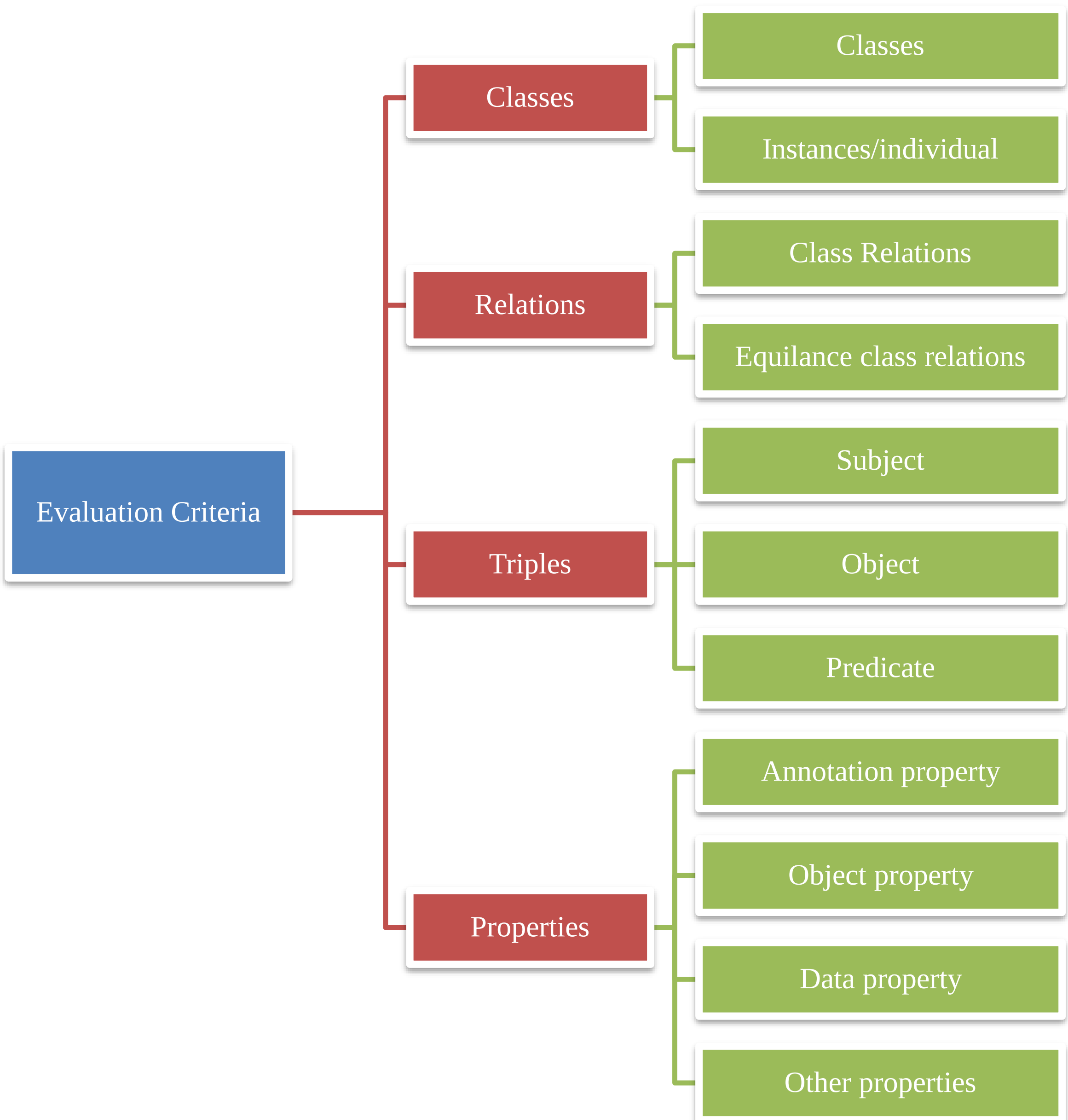


Figure 3.2-1 Proposed Evaluation Criteria

3.3 Structural characteristics:

The proposed criteria for evaluation is based on the structural characteristics and the characteristic are class/concept, individuals, triples, relations between classes and individuals and the properties. The characteristics that are used for this framework are explained in details following.

3.3.1 Concept:

Concept is also called as classes, which are the abstract set or the abstract collection of the things or object in the ontology. Every ontology hierarchy start with the class named "Things" in Protégé. "Things" is the major super class of every ontology in the Protégé. Classes contain other classes and instances in the ontology hierarchy. Classes are also sub divided into the supper class and sub class [65]. Super class is the main class of ontology in which every class is linked in hierarchy. In "chemical information ontology" the classes are atom counting, role, material entity, processual-entity, processual-context, length unit, three dimensional regions and etc.

3.3.2 Individuals:

Individuals (also known as instances) are the objects of the domains. In Protégé individuals can have two different name which refer the same instance [66]. In OWL the individuals/ instance are also known as the original objects in the domain. For example, in "chemical information ontology" the instances are label, string, plainLiteral, two-dimensional-region, temporal-region, creator etc.

3.3.3 Relations:

Relations are the different type of ways an objects can interact or relate to the other objects. For example, an object can use another object they have a is_a relation. [67] In ontologies there are two different types of relations, first is the relation between the classes (how each class interact with the other class.) second is the relation between the class and its instances. The relations in the "Chemical information ontology" are has-part-of, is_a, is_smaller_than, part_of etc.

3.3.4 Triples:

Triples contains the subject, object and the predicate. Triples is like a sentence or the event which can give some kind of information about a resource. [68]

Figure 3.3-1 Triples Structure

In the above figure the relations between the subject, object and predicate is shown. In OWL ontologies subjects are the URI's (Uniform Resource Identifier) resource first part which have some information that can link to the other resource through the predicates. [69]

3.3.5 Properties

Properties define the attributes and features of the concepts in the ontologies. Ontologies properties are the connection between the two or more instances. [70] Properties are the relation between the instances or the objects. They tell us about how the instances can communicate the data and how they link with each other. [69]

The properties that are used in the proposed criteria are Annotation properties, object properties, data properties, reflexive properties, function properties, inverse properties, asymmetric properties and symmetric properties. These are the properties that are used in the proposed evaluation criteria. These are explained in detail below.

3.3.5.1 Annotation Property:

Annotation property gives the information about the concept (class), individuals, ontology itself and the other kind of properties. The information is about the meta data for example, the author (who create the ontology), version of the ontology, the comments and labels etc. the annotation property in owl are *"owl:lable, owl:versionInfo, owl:backwardCompatibleWith, owl:incompatibleWith, OWL:isDefinedBy and so on."* [61] In Protégé while making the ontology one can also defined the annotation properties of ontology.

3.3.5.2 Data Property:

These properties can link the objects with literals. Data property of ontology describe the data related information and describe the relation between two individuals in the ontology and the datatypes. [70] These are the properties that associated with the owl, XML/RDF, HTML schemas. Protégé can support these types of properties and users can easily have defined these properties while establishing the ontology. Data property can give the information about the data and the relationships between the individuals. Some of the data properties are "owl:topDataProperty, :hasName, :hasDataType, :hasFeatureValue, :hasCorrdinates, :hasUncertainValue etc."

3.3.5.3 Object Property:

The object property is used to pair or connect the individuals or objects with each other in the ontology. Protégé can support these types of properties and users can easily have defined these properties while establishing the ontology. Also Protégé can show the hierarchy of object properties and show all the properties in the imported ontology. Some of the object properties are "*adjacentTo, conformsTo, hasAttributes, contains, hasPart, hasIntegralPart, isattributeOf, isVariantOf* etc."

3.3.5.4 Reflexive Property:

Reflexive property is the property which can relate the object with itself. Protégé can support these types of properties and users can easily have defined these properties while establishing the ontology. For example, an object A can relate to itself with the property P. Some of the reflexive property of "Hymenoptera Anatomy Ontology" are "*connected via conjunctiva, integral part of*".

3.3.5.5 Function Property:

Using this property, at most one object or instance can connect or relate to the other object of instance. Protégé can support these types of properties and users can easily have defined these properties while establishing the ontology. This property contains some characteristics of objects. The function properties in the "General formation ontology" are "objects to, exist at, framed by, has_functional_item, occupies" etc.

3.3.5.6 Inverse Property:

It is like the reverse property. For example, if object A and object B are connected with some property inverse property is the inverse of the connected property like the inverse property of childHas is childOf. Protégé can support these types of properties and users can easily have defined these properties while establishing the ontology. This property is not very important but it has some instance/individuals characteristics and also Protégé supports this property in owl ontologies.

3.3.5.7 Symmetric Property:

Symmetric property says that if an object A is connected with the property P to the other object B than object B is also connected with the object A with the same property P. Protégé can support these types of properties and users can easily have defined these properties while establishing the ontology. Like other properties symmetric property is also link with the object property characteristics. For example, the symmetric properties in the "chemical information ontology" are "is_variant_of, is_stereoisomer_of etc."

3.3.5.8 Transitive Property:

Transitive property says that If an object A connected with a property P to an object B, and object B is connected with an object C than object A and C are also connected with each other with the same property P. Protégé can support these types of properties and users can easily have defined these properties while establishing the ontology. Like other properties symmetric property is also link with the object property characteristics.

3.3.5.9 Asymmetric Property:

Asymmetric property relates the objects in an opposite to the symmetric property. In asymmetric property if an object A is connected with the property P to the other object B than object B is not connected with the object A with the same property P. Protégé can support these types of properties and users can easily have defined these properties while establishing the ontology. Like other properties symmetric property is also link with the object property characteristics.

The following table shows the short definition of terms for understanding.

Table 3.3-1 Structural Characteristics and their definitions

Terms	Definition	
Class	In Protégé class/concept is the main node of the ontology. The first main node is called super class. In Protégé super class is "things". For example atom counting, role, material entity, processual-entity, processual-context, length unit, three dimensional regions etc.	
Instances/ individual	Instances are the individuals or objects.	
Class relations	It is the relationship between the classes and objects.	
Triples	Subject	Describe the resource in the form of URI.
	Object	It is the property that is attached to the subject.
	Predicate	Type of relationship between triples.
Properties	Annotation	Annotation property gives the information about the concept (class), individuals, ontology itself and the other kind of properties.
	Object	The object property is used to pair or connect the individuals or objects with each other in the ontology.
	Data	These properties can link the objects with literals.
	Function	One object or instance can connect or relate to the other object or instance through this property.
	Reflexive	The property which can relate the object with itself.
	Symmetric	If an object A is connected with the property P to the other object B than object B is also connected with the object A with the same property P.
	Transitive	If an object A connected with a property P to an object B, and object B is connected with an object C than object A and C are also connected with each other with the same property P.
	Asymmetric	If an object A is connected with the property P to the other object B than object B is not connected with the object A with the same property P
	Inverse	If object A and object B are connected with some property inverse property is the inverse of the connected property like the inverse property of childHas is childOf.

Chapter 4

Implementation and Results

CHAPTER 4: IMPLEMENTATION AND RESULTS

4.1 Implementation:

In this section we have execute the queries on the selected ontologies on Protégé and discuss the results. For the sake of understanding, we show the results of one ontology and explain the results of other ontologies in the later. The results of SPARQL queries are shown below

4.1.1 Importing ontologies:

Ontologies can be importing into the Protégé by different ways. For example, import the ontologies using a URI, importing an ontology from PC, loading from workspace or from the already provided library.

Below shows the figure of the software which we can load the desired ontology to perform the evaluation criteria.

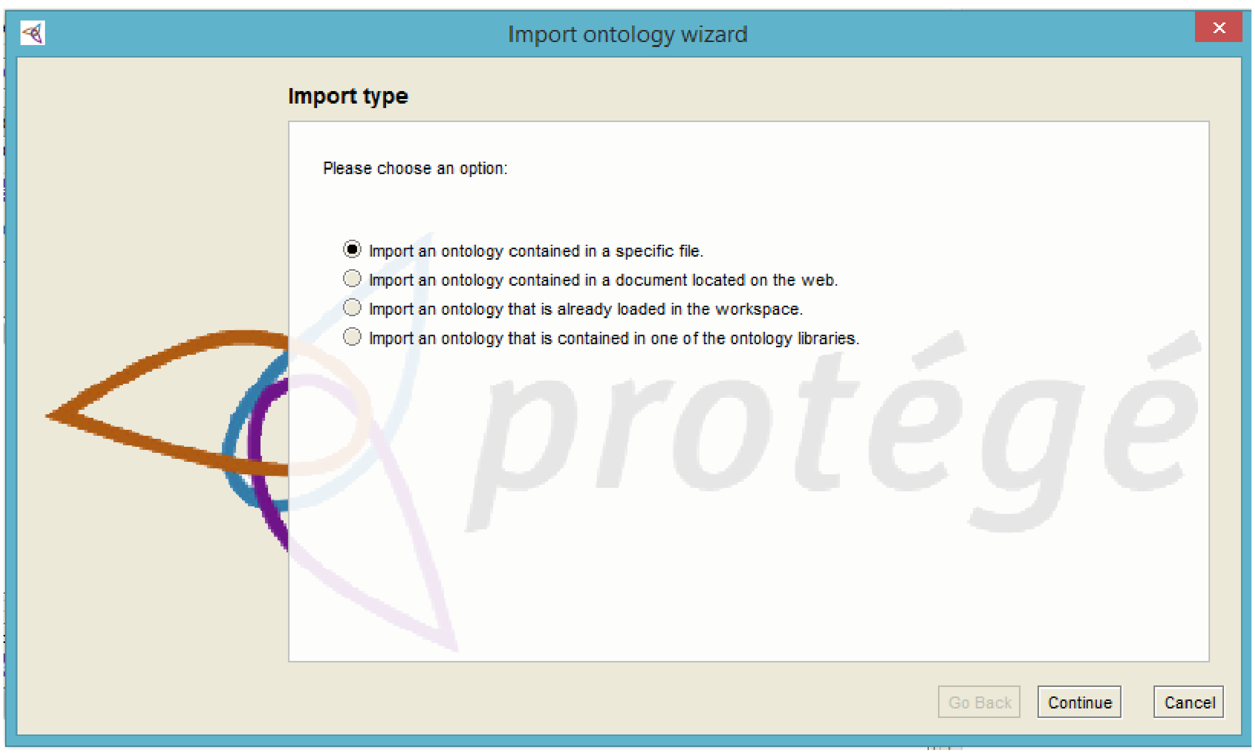


Figure 4.1-1 Importing ontology interface

4.1.2 Queries interface for classes and their results:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
SELECT ( count(DISTINCT ?class) as ?count )
{ ?class a owl:Class }
```

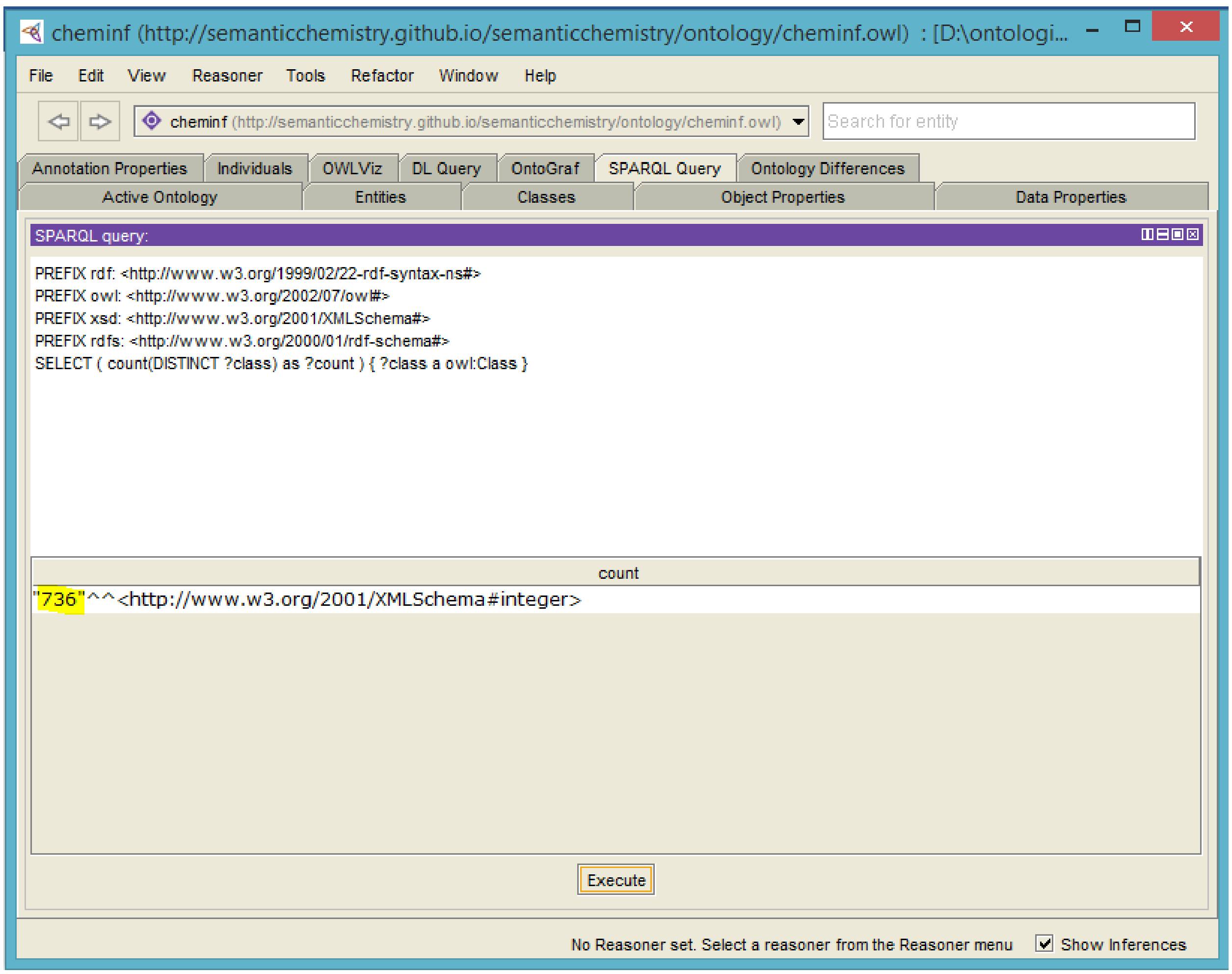


Figure 4.1-2 Interface of counting number of Concepts

4.1.3 Queries interface for instances and their results:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
 PREFIX owl: <http://www.w3.org/2002/07/owl#>
 PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
 PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
 SELECT (count(DISTINCT ?instance) as ?count_instance)
 {?instance a ?class }
```

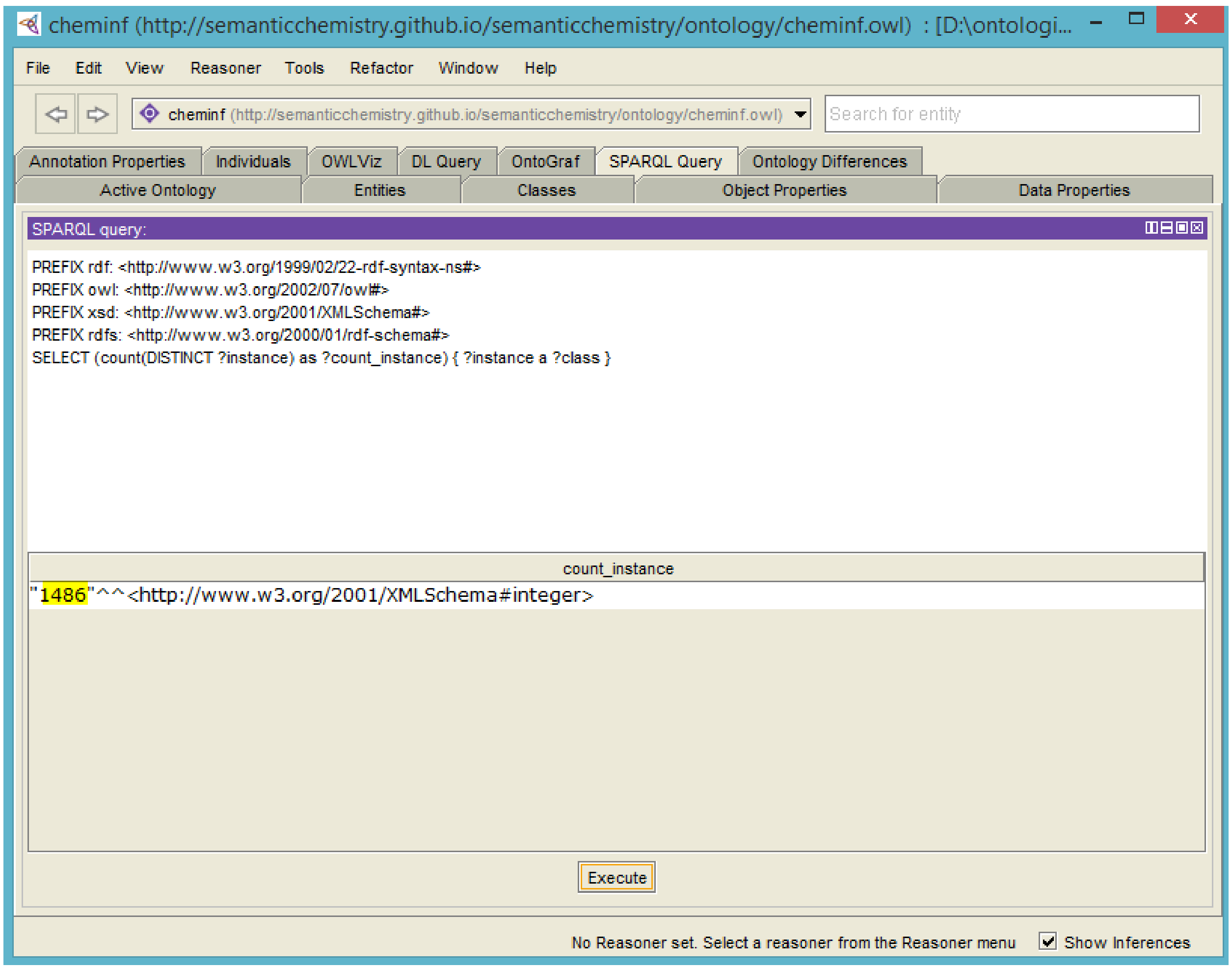


Figure 4.1-3 Interface of counting number of Individuals

4.1.4 Queries interface for Subject and their results:

PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>

PREFIX owl: <http://www.w3.org/2002/07/owl#>

PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT (count (DISTINCT ?s) as

?count_subject) { ?s ?p ?o }

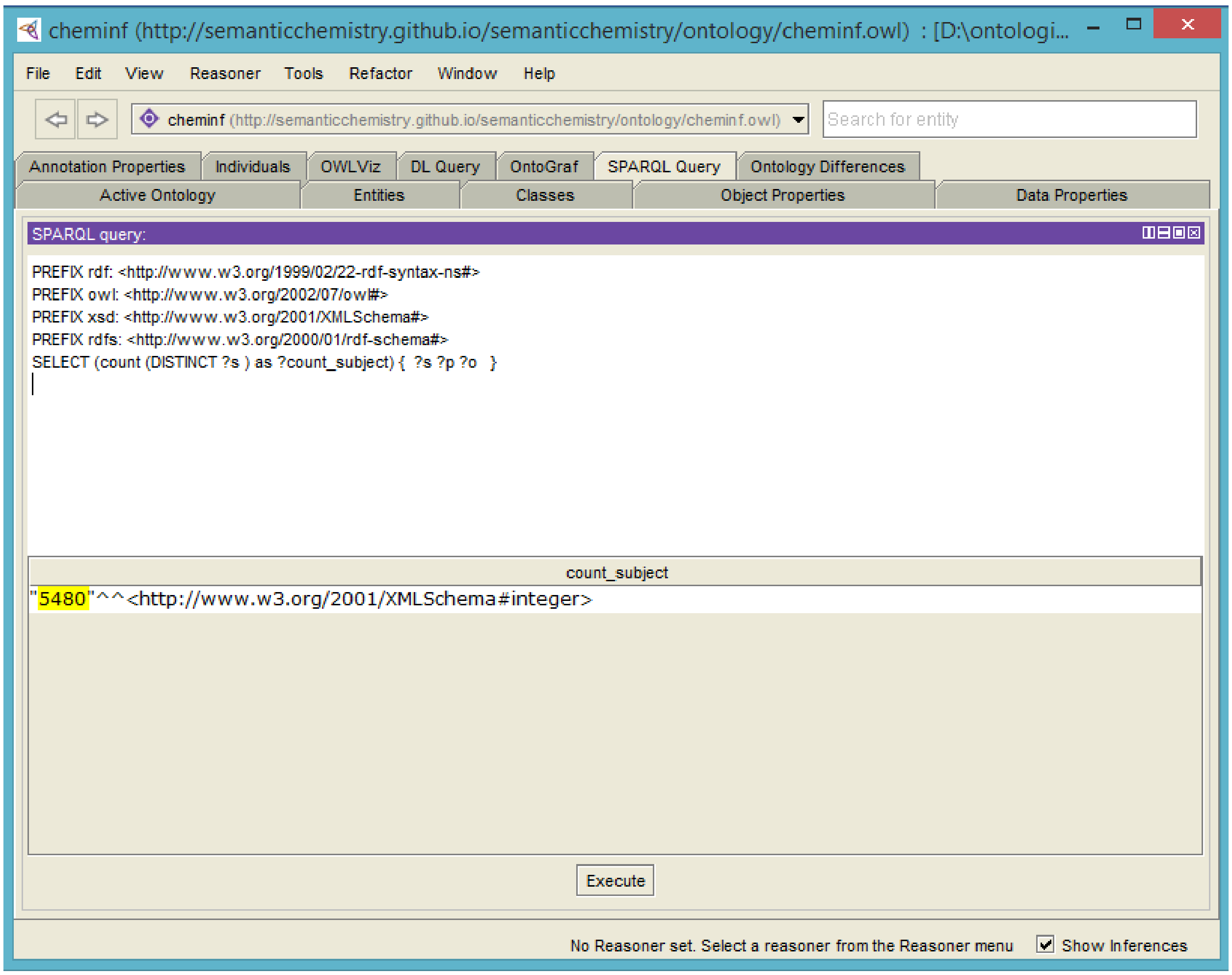


Figure 4.1-4 Interface of counting number of Subjects

4.1.5 Queries interface for object and their results:

PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>

PREFIX owl: <http://www.w3.org/2002/07/owl#>

PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT (count (DISTINCT ?o) as

?count_object) { ?s ?p ?o }

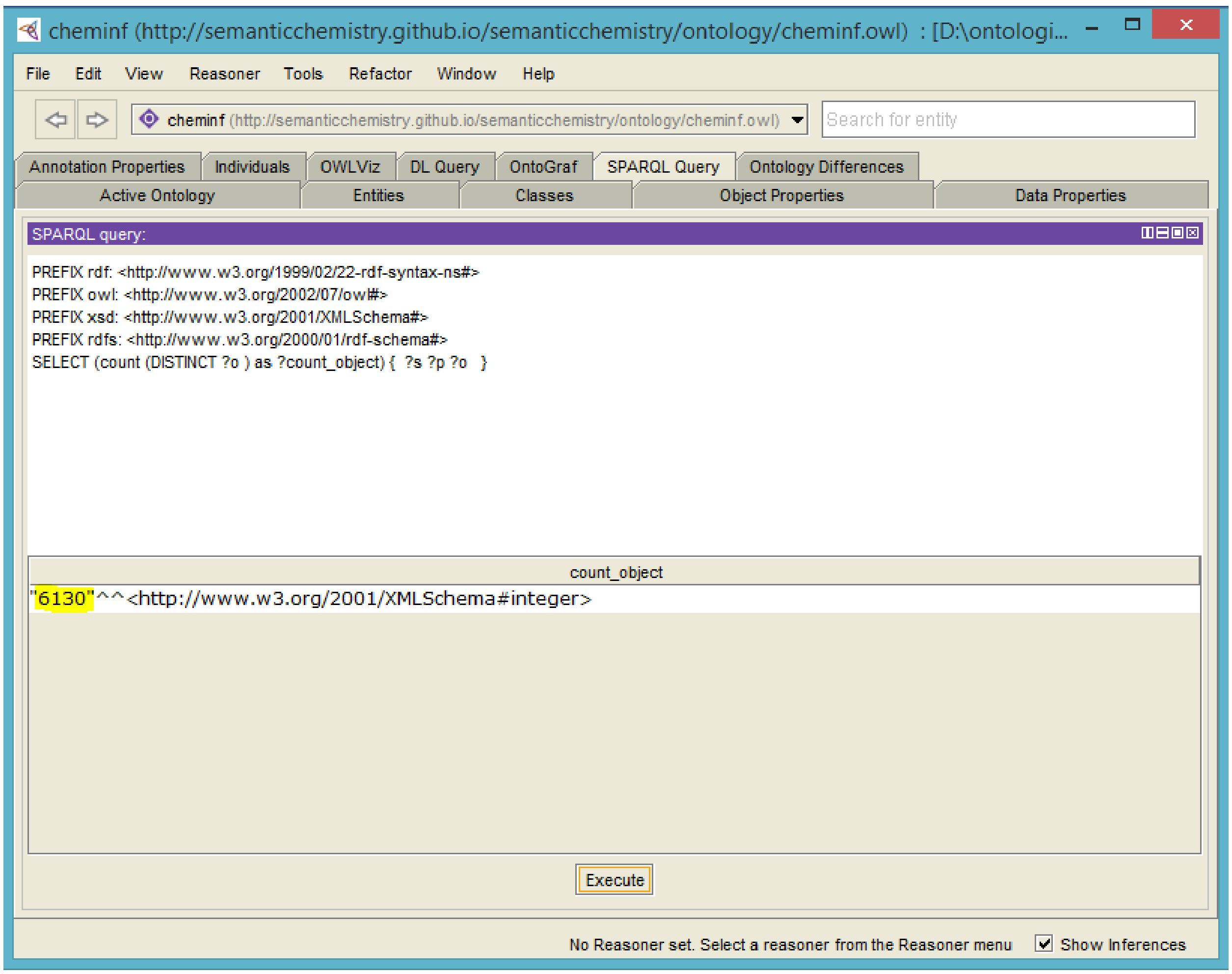


Figure 4.1-5 Interface of counting number of objects

4.1.6 Queries interface for predicate and their results:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
SELECT (count (DISTINCT ?p ) as
?count_predicate) {  ?s ?p ?o   }
```

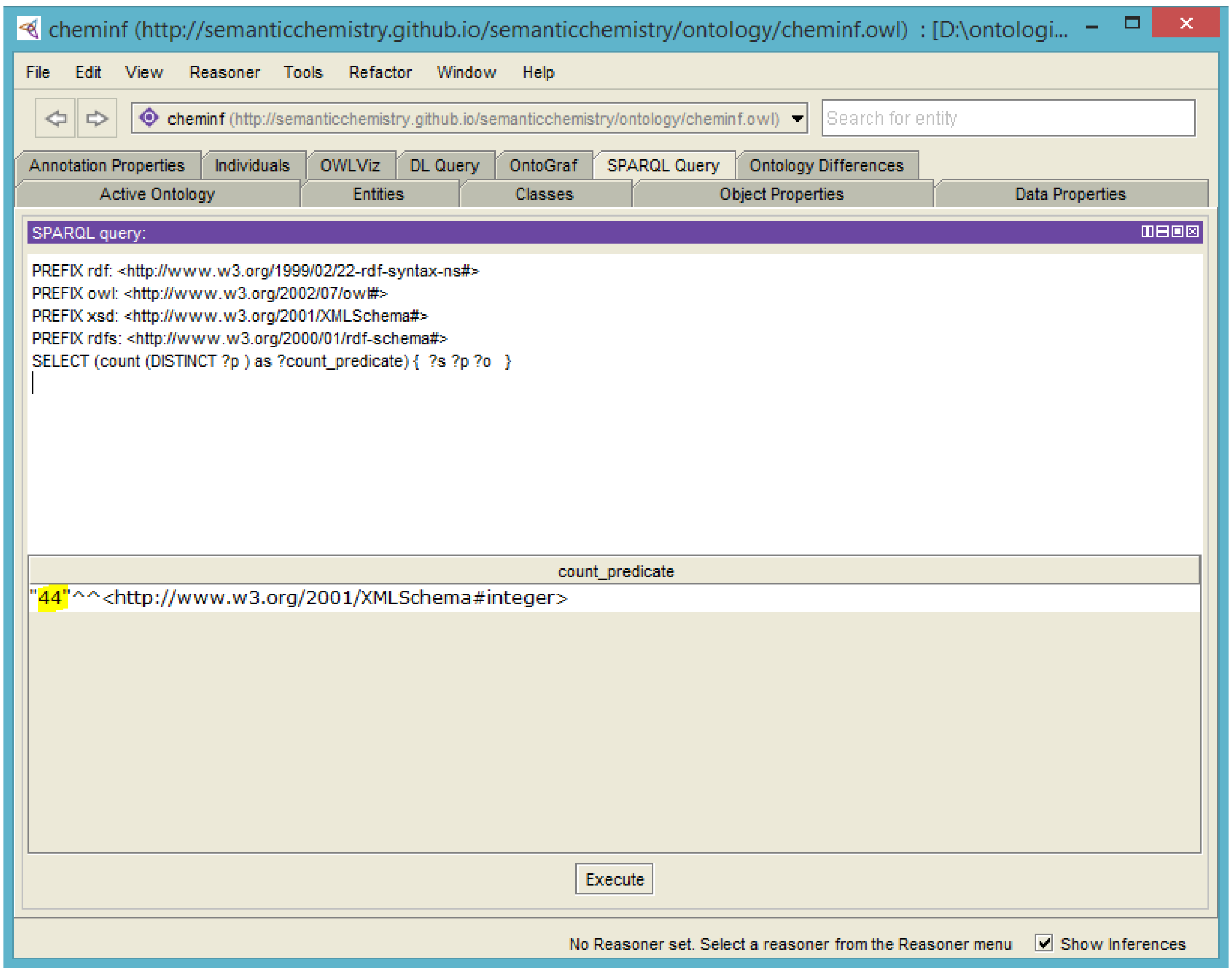


Figure 4.1-6 Interface of counting number of predicates

4.1.7 Queries interface for Triples and their results:

PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>

PREFIX owl: <http://www.w3.org/2002/07/owl#>

PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT (count (DISTINCT *) as

?Triple_Count) { ?s ?p ?o }

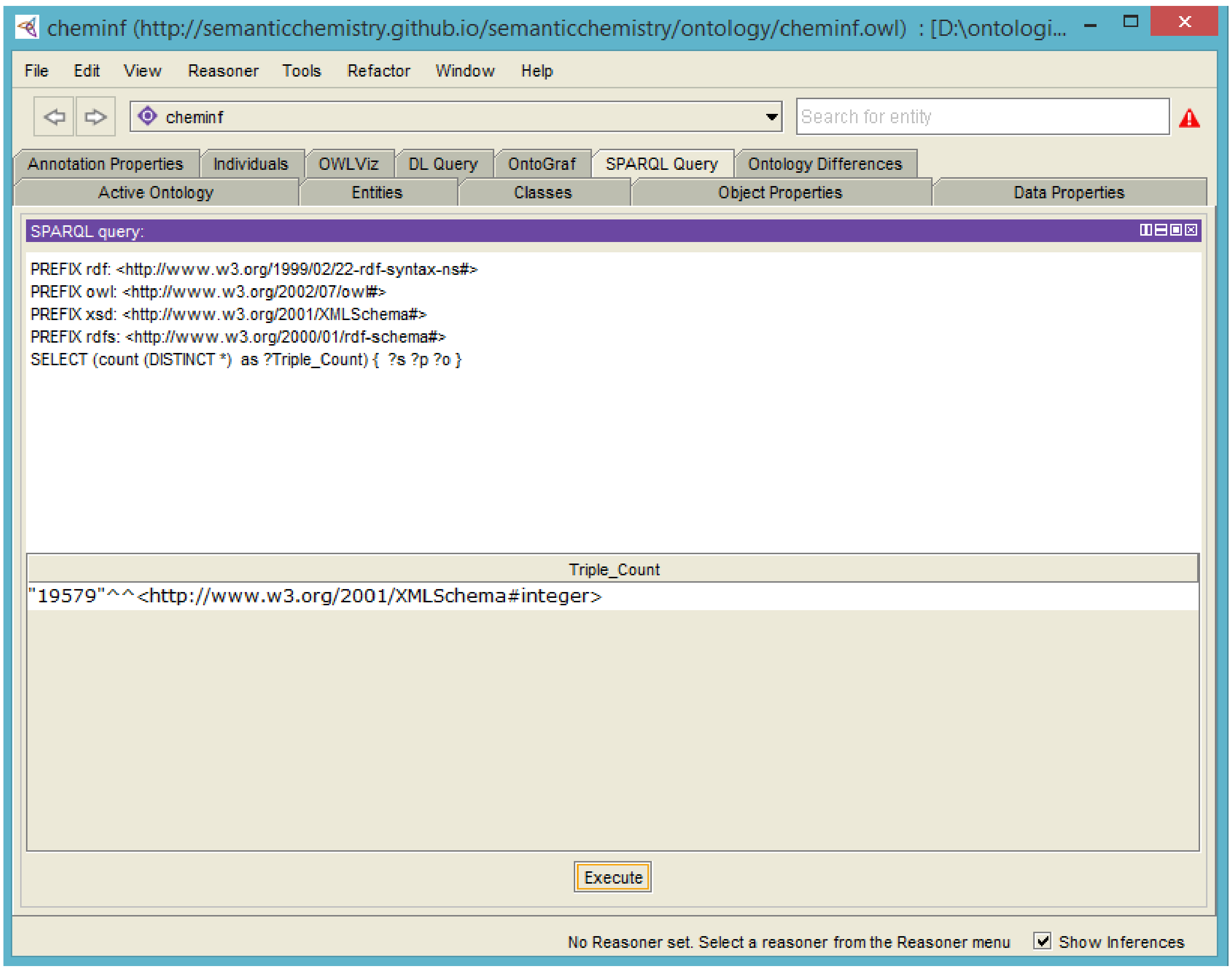


Figure 4.1-7 Interface of counting number of triples

4.1.8 Queries interface for Annotation property and their results:

PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>

PREFIX owl: <http://www.w3.org/2002/07/owl#>

PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT (count(DISTINCT ?x) as ?count)

{?x a owl:AnnotationProperty}

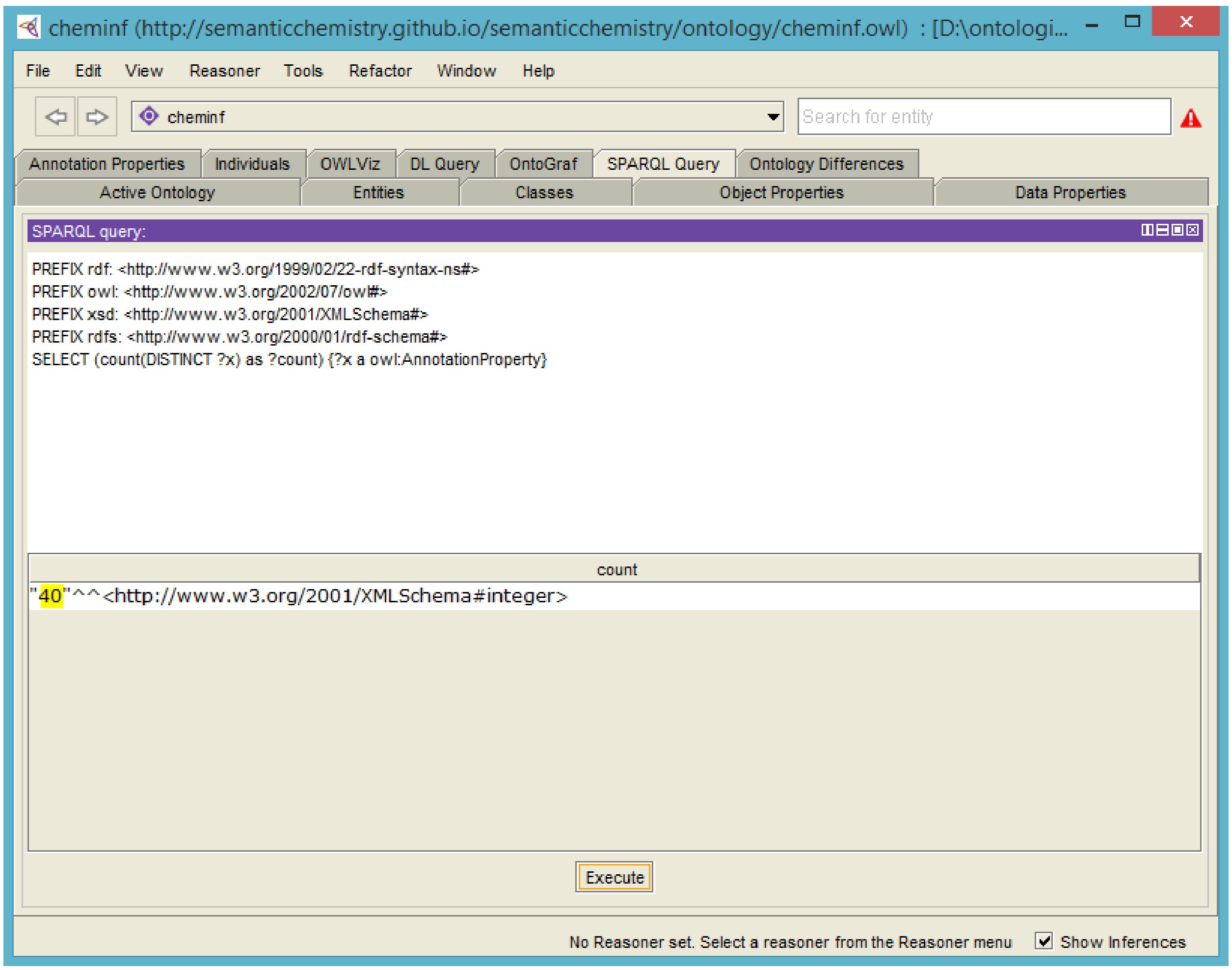


Figure 4.1-8 Interface of counting number of annotation property

4.1.9 Queries interface for object property and their results:

PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>

PREFIX owl: <http://www.w3.org/2002/07/owl#>

PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT (count(DISTINCT ?x) as ?count)

{?x a owl:ObjectProperty}

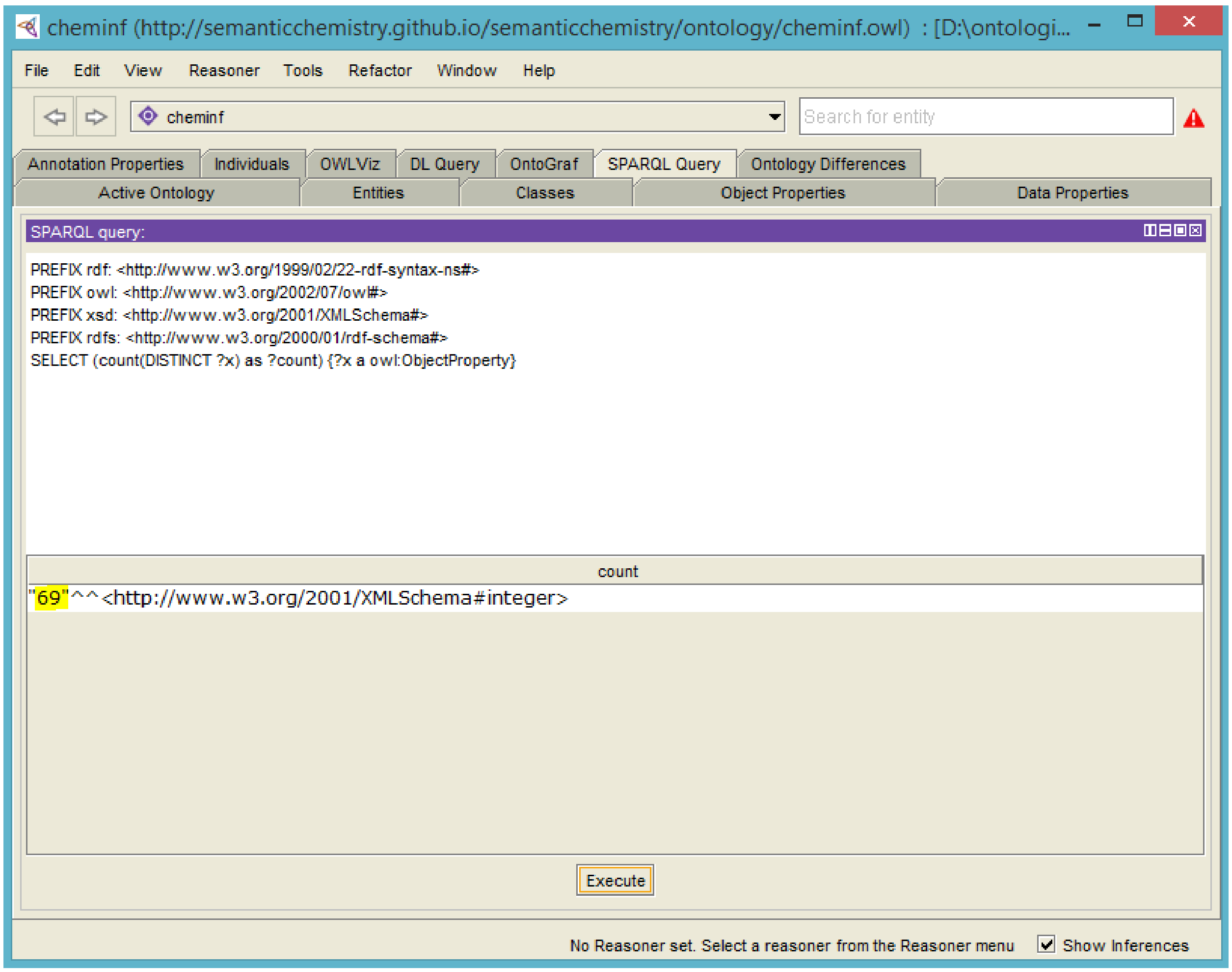


Figure 4.1-9 Interface of counting number of object property

4.1.10 Queries interface for data property and their results:

PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>

PREFIX owl: <http://www.w3.org/2002/07/owl#>

PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT (count(DISTINCT ?x) as ?count)

{?x a owl:DataProperty}

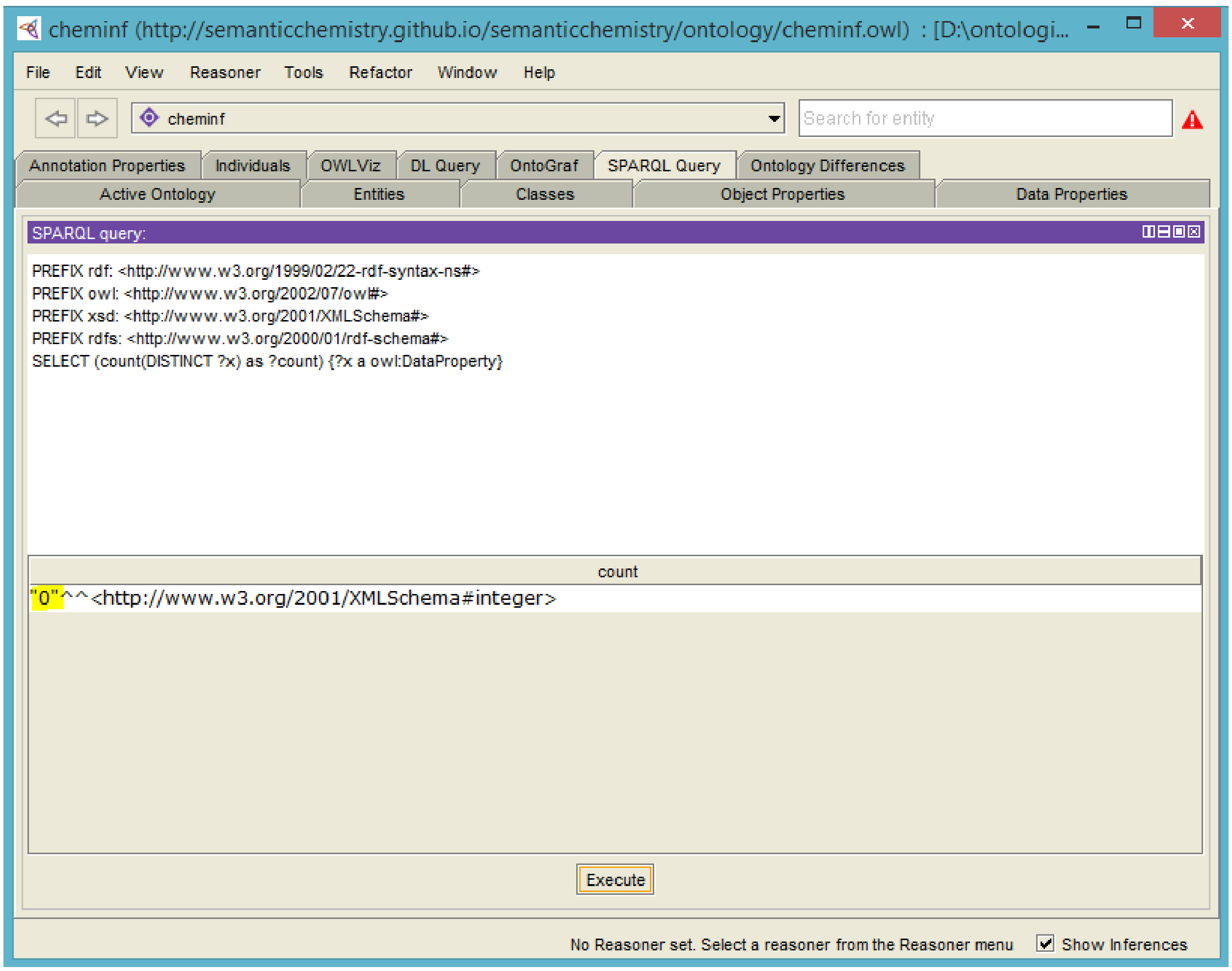


Figure 4.1-10 Interface of counting number of data property

4.1.11 Queries interface for inverse property and their results:

PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>

PREFIX owl: <http://www.w3.org/2002/07/owl#>

PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT (count(DISTINCT ?Inverse_property) as

?count_Inverse_property) {?Inverse_property a owl:InverseProperty}

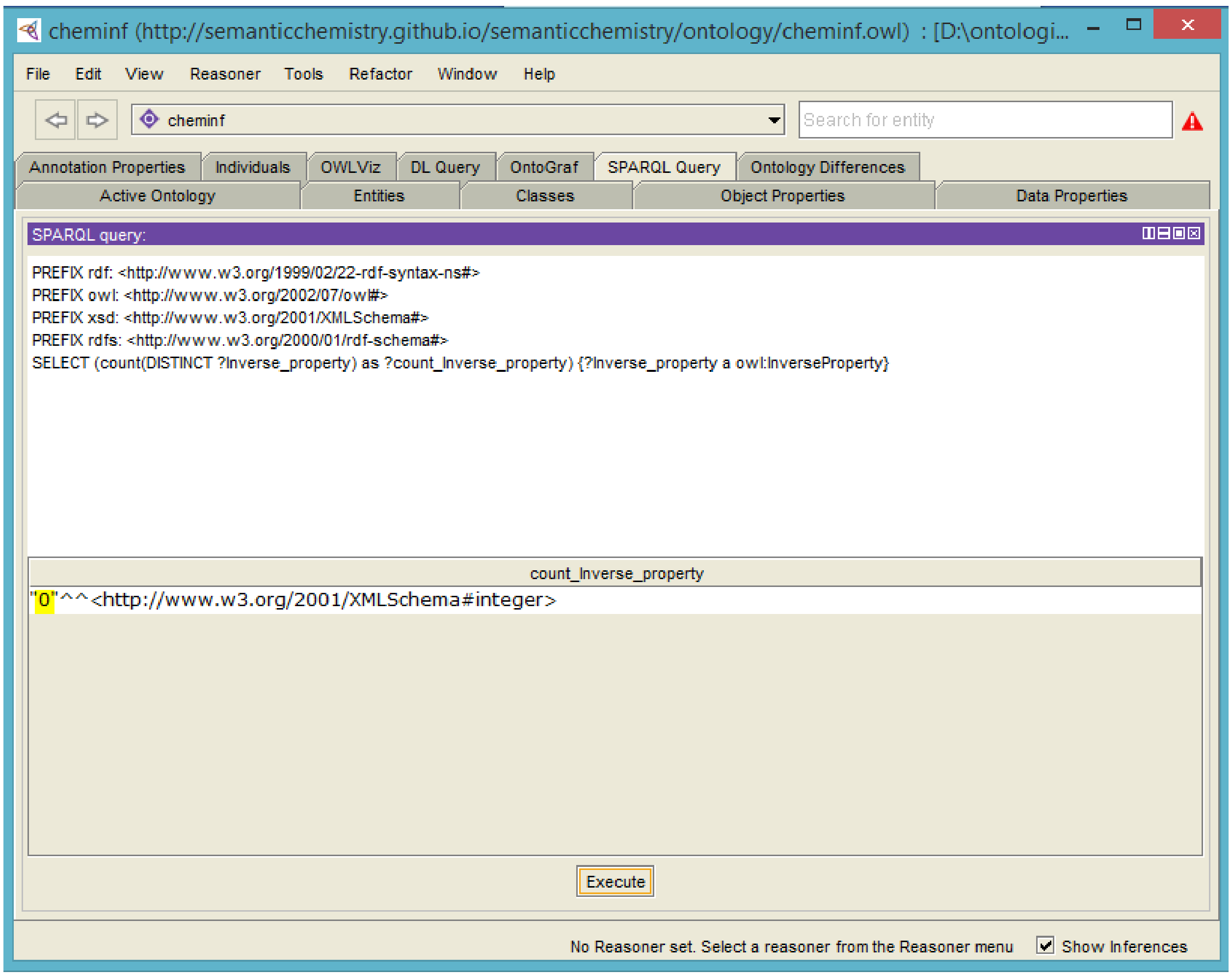


Figure 4.1-11 Interface of counting number of inverse property

4.1.12 Queries interface for functional property and their results:

PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>

PREFIX owl: <http://www.w3.org/2002/07/owl#>

PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT (count(DISTINCT ?functional_property) as

?count_functional_property) {?functional_property a owl:FunctionalProperty}

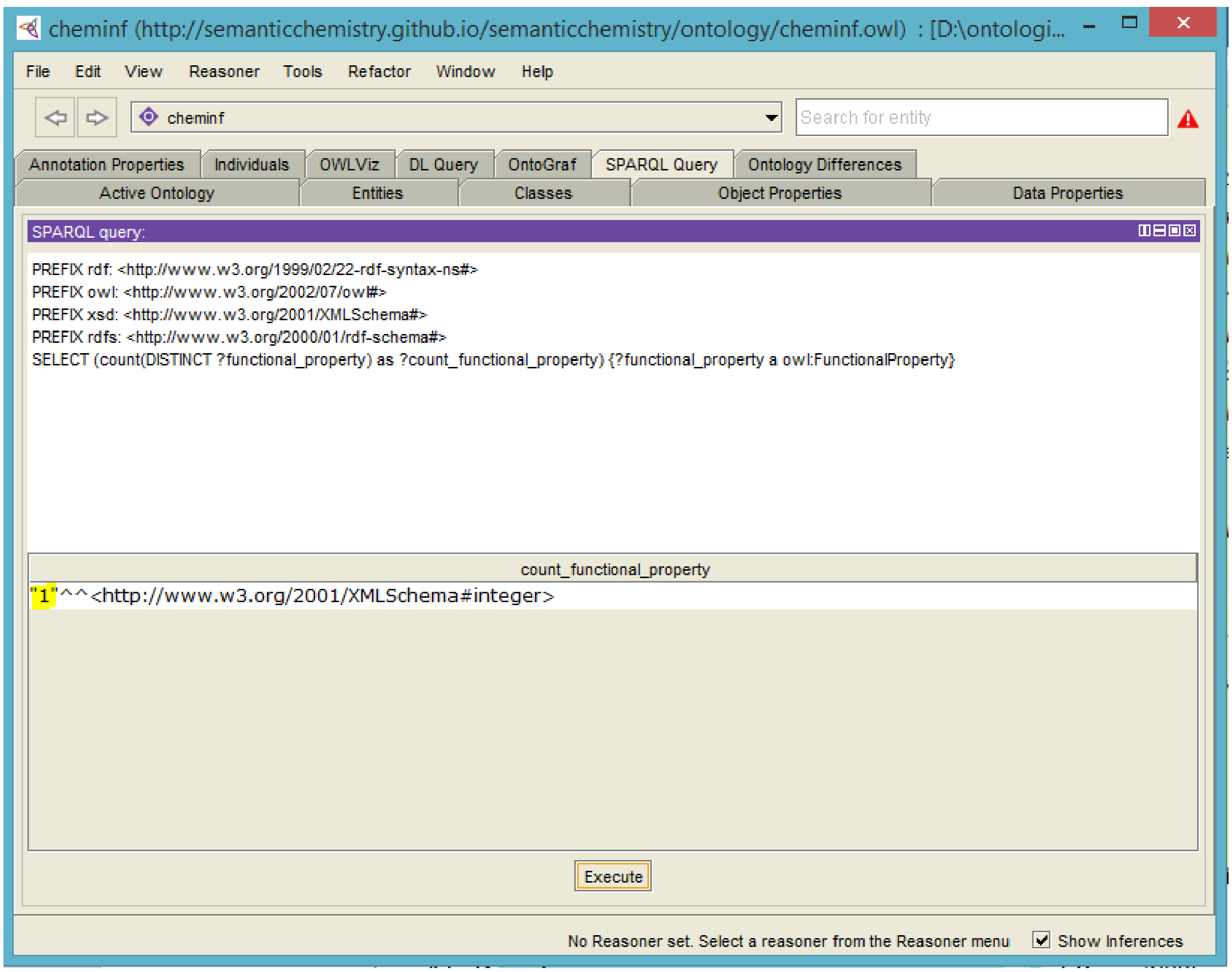


Figure 4.1-12 Interface of counting number of functional property

4.1.13 Queries interface for symmetric property and their results:

PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>

PREFIX owl: <http://www.w3.org/2002/07/owl#>

PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT (count(DISTINCT ?Symme

tic) as ?count_Symmetic_property)

{?Symmetic a owl:SymmetricProperty}

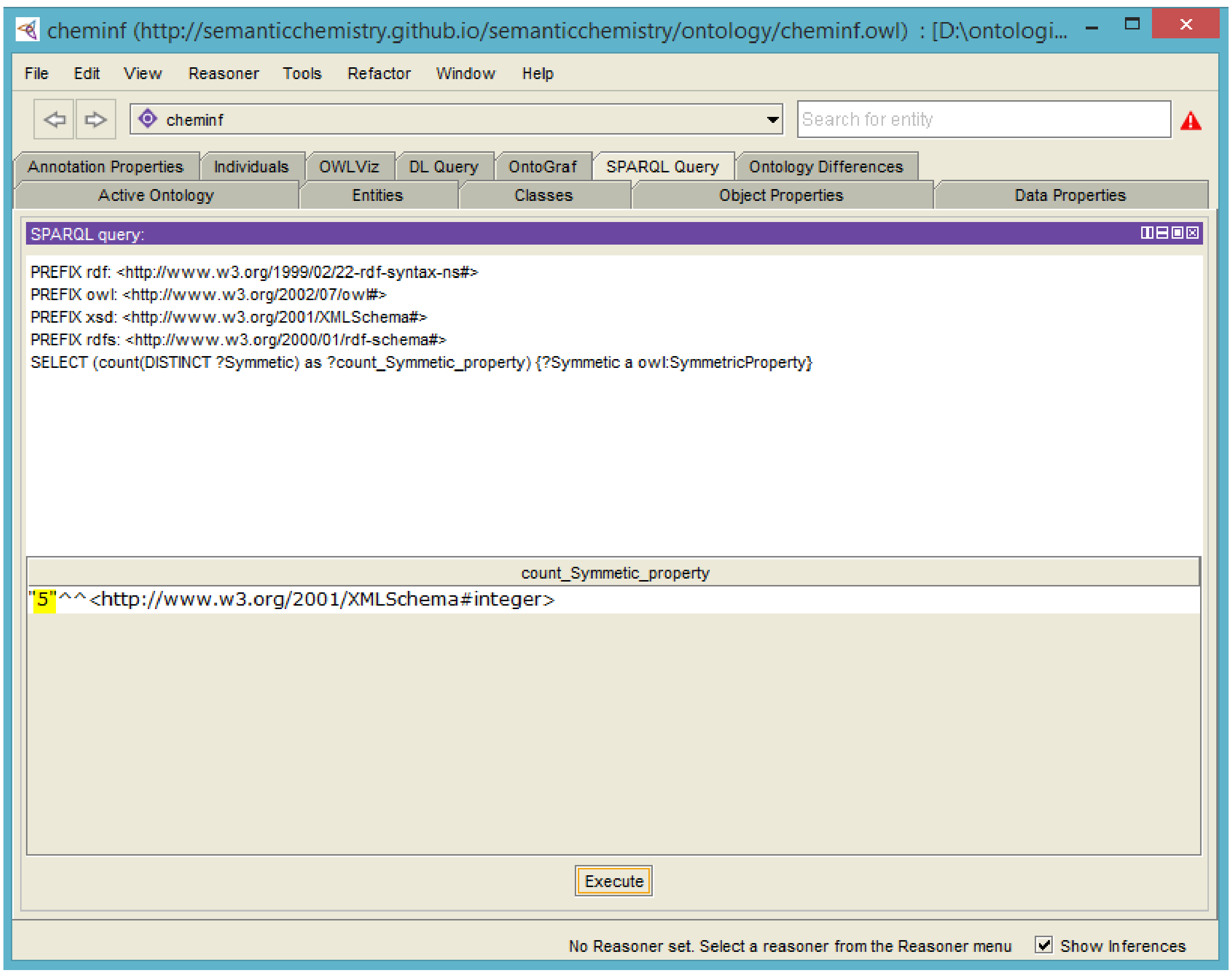


Figure 4.1-13 Interface of counting number of symmetric property

4.1.14 Queries interface for asymmetric property and their results:

PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>

PREFIX owl: <http://www.w3.org/2002/07/owl#>

PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT (count(DISTINCT ?asymetric) as ?count_asymetric_property)

{?asymetric a owl:AsymmetricProperty}

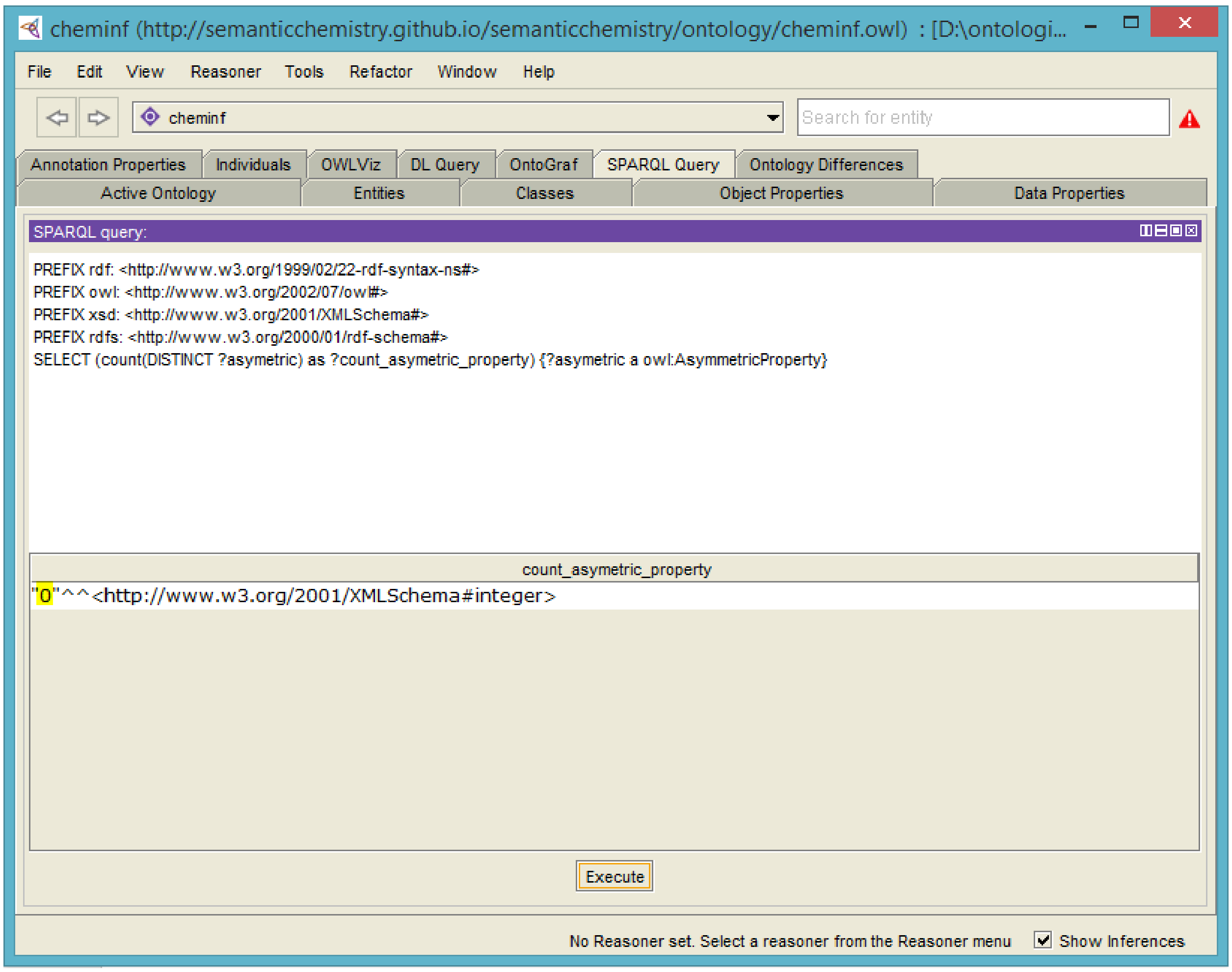


Figure 4.1-14 Interface of counting number of asymmetric property

4.1.15 Queries interface for Transitive property and their results:

PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>

PREFIX owl: <http://www.w3.org/2002/07/owl#>

PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT (count(DISTINCT ? Transitive) as ?no)

{? Transitive a owl:TransitiveProperty}

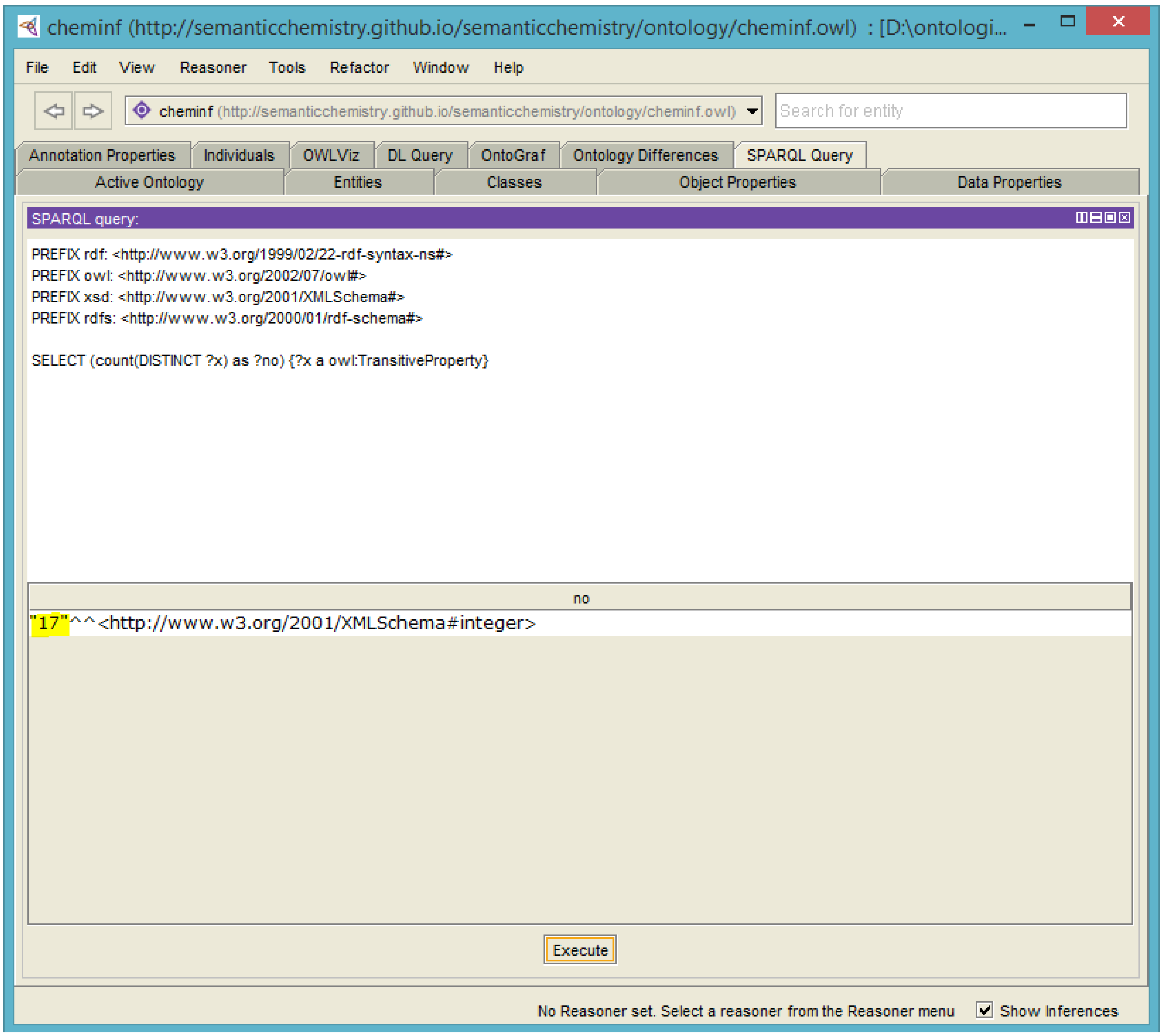


Figure 4.1-15 Interface of counting number of transitive property

4.1.16 Queries interface for reflexive property and their results:

PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>

PREFIX owl: <http://www.w3.org/2002/07/owl#>

PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT (count(DISTINCT ?reflexive) as ?count_reflexive_property)

{?reflexive a owl:ReflexiveProperty}

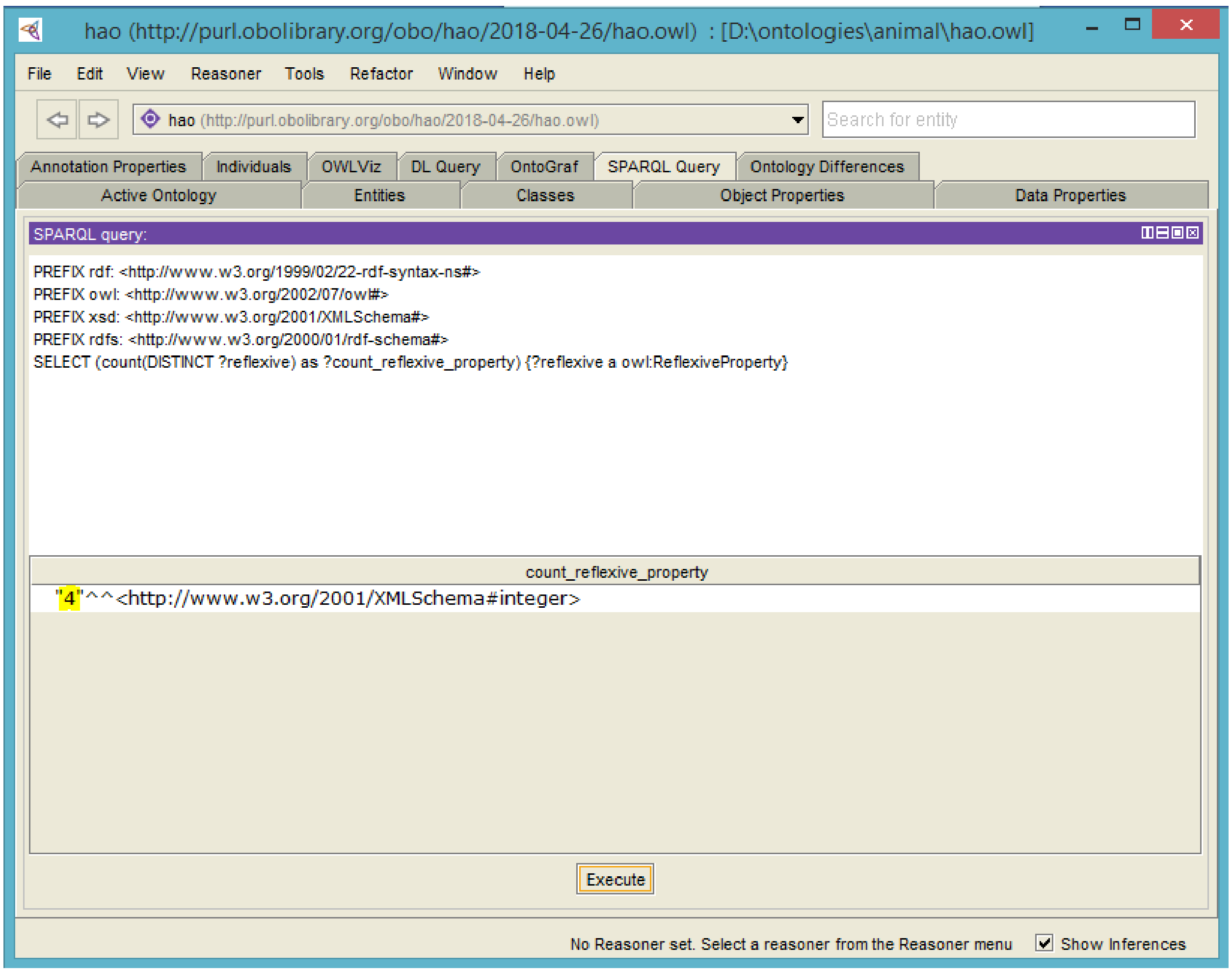


Figure 4.1-16 Interface of counting number of reflexive property

Ontology Metric

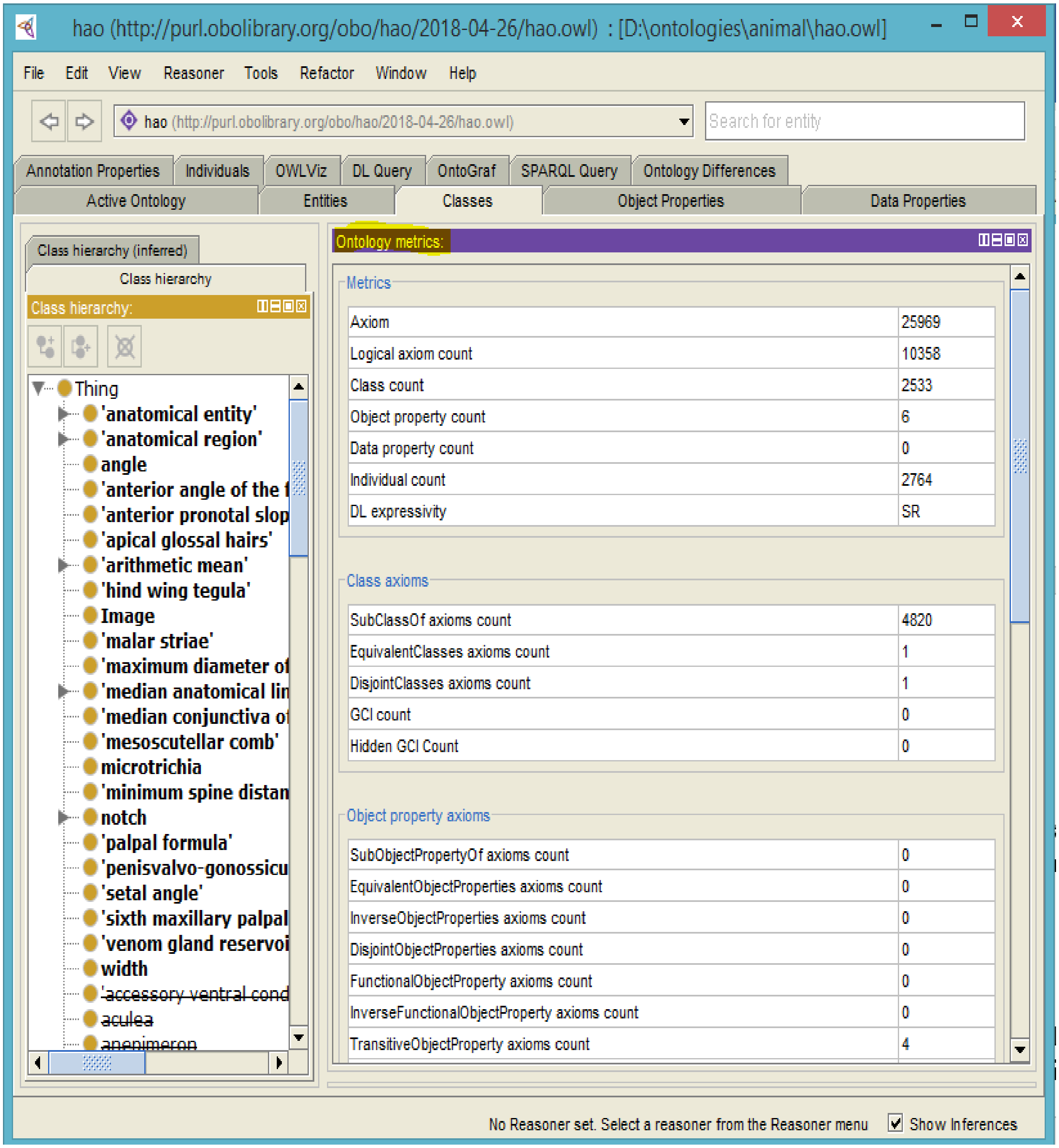


Figure 4.1-17 Ontology matric

4.2 Data Gathering

For the experimental purpose the ontologies data gathered from different online available portals for example NCBO, OBO foundry. NCBO [62] is the open source library for the ontologies. It has 992 ontologies on different domains and different types. NCBO has categorize the ontologies on different formats and different domains so the searching is very easy. NCBO [63] can also be used for mapping, annotate your bio data into ontology, as a recommender and to browse the ontology. NCBO portal also used in the US. National library of medicine, National institute of health (NIH), Applied physics library (API) and LIRMM. NCBO portal is also linked with other ontology portals.

Obo foundry [64] is the open bio-medical and biological web portal for ontologies. Obo foundry is linked with OntoBee website. OntoBee has a separate ontology evaluation criterion. In OBO Foundry ontologies are represent in the form of tables and each ontology has different formats so can user easily found what they need. Each ontology that is available in the OBO foundry is documented and also linked with GitHub. The table of ontologies in the obo foundry is following.

For our experimentation we select 14 different domains related ontologies. The following table can show the name of the ontology, their formats their version (try to evaluate the latest version of the ontologies), the categories of the ontologies and the link of the ontology. The domains of the evaluation which are selected for the framework are human anatomy (Bio-medical related domain), Animals ontologies (Animal related domain), Chemical ontologies (Chemical and physics related domains), Neurological disease ontologies (Medical related domain) and Plant ontology (Biological domain).

Table 4.2-1 Selected ontologies for evaluation

Sr. #	Ontology Title	Category	File name	Version/modified date
1	Collembola Anatomy Ontology	Human Anatomy	Cao.owl	Version 1.2/ 29-03-2019
2	Subcellular Anatomy Ontology		SAO.owl	Version 1.2/ 13-03-2018
3	Anatomic Ontology for Human Lung Maturation		human_ bioportal.owl	Version 1/ 24-03-2018
4	Anatomic Entity Ontology		Aeo.owl	Version 1/ 22-11-2017
5	General formal ontology of biology	Animal	Gfo_bio.owl	1.1 3-2-2010
6	Planarian Anatomy and developmental Stage Ontology		Plana.owl	25-05-2019
7	Hymenoptera Anatomy Ontology		Hao.owl	26-4-2018
8	Chemical Information Ontology	Chemical	Cheminf.owl	Version 1.9.3 21-8-2019
9	NanoParticale Ontology		npo-2011-12-08_inferred.owl	Version 17-8-2012
10	Alzheimer's Disease Ontology	Neurological disease	Alzheimer Ontology v15R-xml_merged.owl	Version 1.1.1 23-7-2013
11	Epilepsy and Seizure Ontology		EpSO_v1.1.owl	Version 1.0 1-9-2017
12	Neurodegenerative Disease Data Ontology		NDDO.owl	Version 0.2 03-06-2019
13	Flora Phenotype Ontology	Plant	Flopo.owl	Version 0.9 6-3-2016
14	Plant Diversity Ontology		PlantDiversityOntology.owl	30-4-2015

4.3 Results

The results of the queries applied to all the selected ontology are following:

4.3.1 Classes and individuals

Table 4.3-1 Results of classes and individuals

Sr. #	Ontology title	Category	Classes	Distinct Classes	Individual	Distinct Individual	Total
1	Collembola Anatomy Ontology	Human Anatomy	4157	998	9876	1606	16637
2	Sub-cellular Anatomy Ontology		5917	790	15490	1352	23549
3	Anatomic Ontology for Human Lung Maturation		1389	295	2901	316	4901
4	Anatomic Entity Ontology		982	250	4256	624	6112
5	General formal ontology of biology	Animal's Ontology	970	199	1701	412	3282
6	Planarian Anatomy and developmental Stage Ontology		2376	545	13619	1810	18350
7	Hymenoptera Anatomy Ontology		17708	2534	72438	15467	108147
8	Chemical Information Ontology	Chemical's Ontology	2821	736	7610	1486	12653
9	NanoParticale Ontology		35649	2462	59676	5633	103420
10	Alzheimer's Disease Ontology	Neurological disease	6440	1608	16726	2465	27239
11	Epilepsy and Seizure Ontology		5092	1455	9783	2149	18479
12	Neurodegenerative Disease Data Ontology		7960	1755	18398	4444	32557
13	Flora Phenotype Ontology	Plant's Ontology	196354	50755	452232	147591	846932
14	Plant Diversity Ontology		14167	380	112110	13068	139725

4.3.1.1 Graphical representation of the above class table:

Below graph 4.3-1 can represent he concepts and individuals of the anatomy related domain. The number of classes of SAO is higher than other ontologies and the number of individuals of CAO ontology is higher than others.

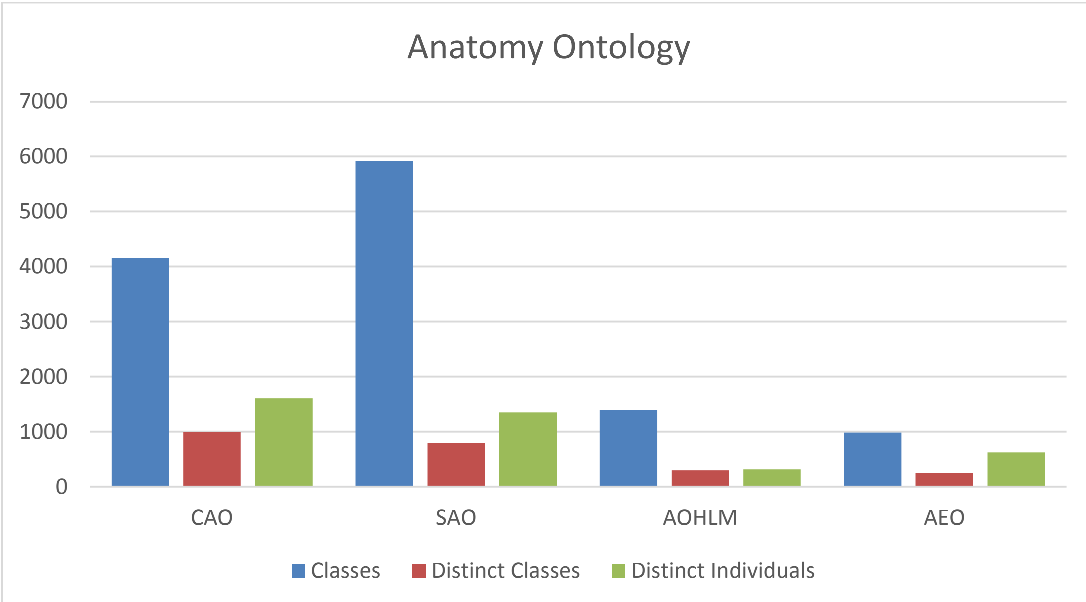


Figure 4.3-1 Graph of class and individuals of anatomy ontology

The following graph 4.3-2 can represent the animal related ontologies class and individuals count. According to the results the HAO ontology has more number of classes and individuals.

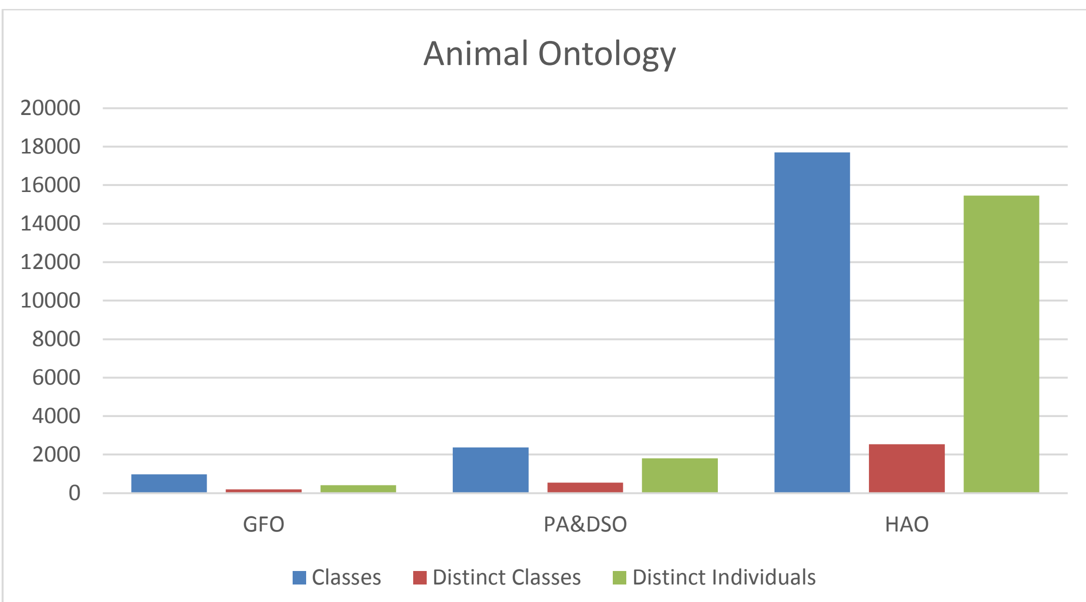


Figure 4.3-2 Graph of class and individuals of animal ontology

The following graph 4.3-3 can represent the results of chemical ontology classes and individuals. The NPO ontology has more number of classes and individuals as compared to CIO ontology.

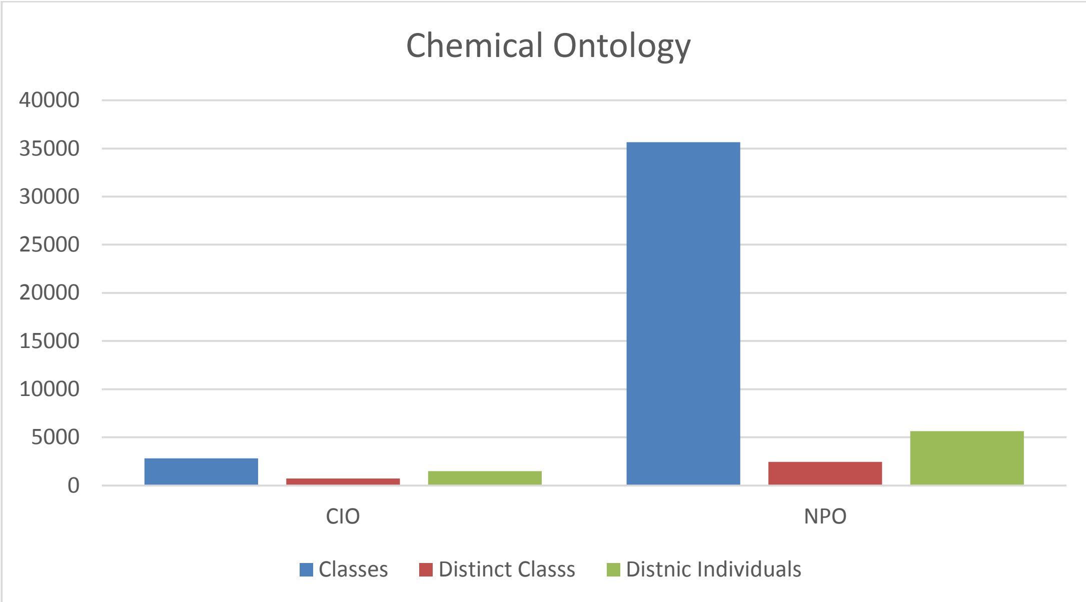


Figure 4.3-3 Graph of class and individuals of chemical ontology

The following graph 4.3-4 shows the class and individuals of the neurological domain related ontologies. The results show that the NDD ontology has more number of classes and individuals as compare to the other ontologies.

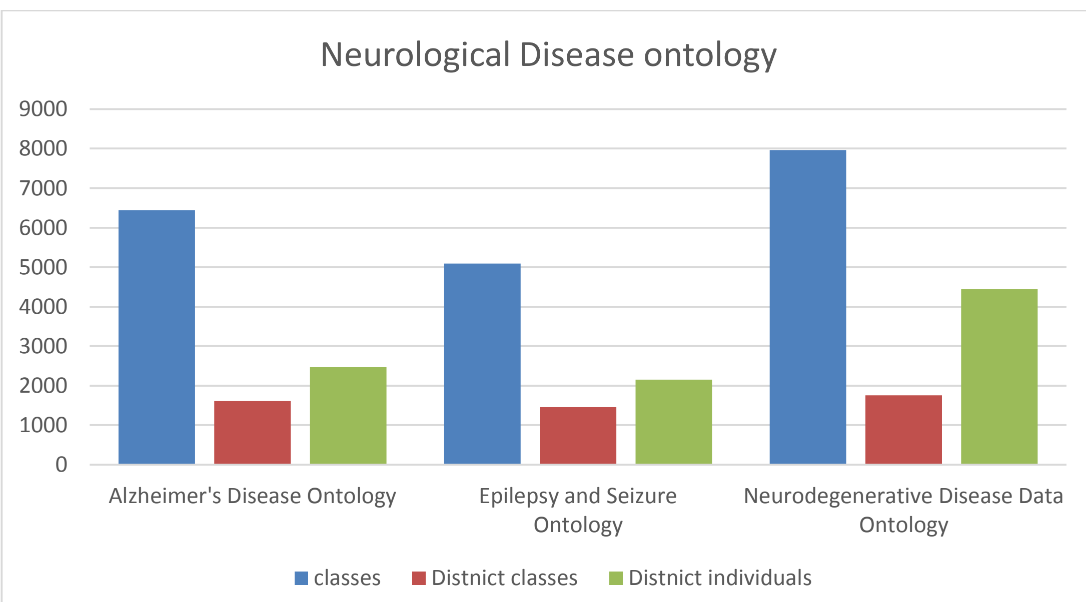


Figure 4.3-4 Graph of class and individuals of neurological disease ontology

The following graph 4.3-5 show the results of the plant's related domain ontologies. The results show that the flora phenotype ontology has more number of classes/concepts and individuals/instances.

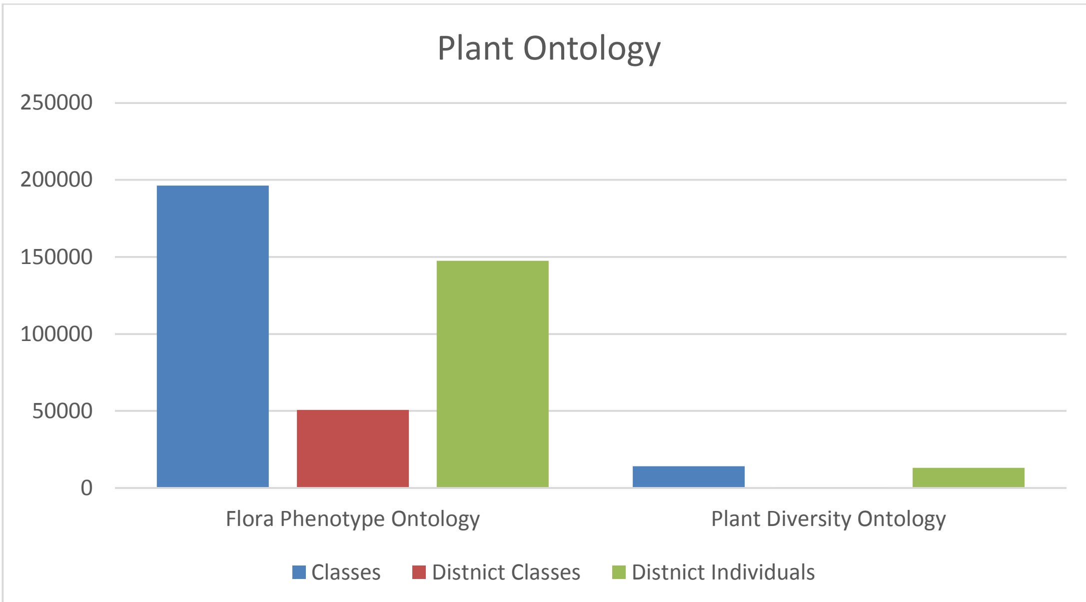


Figure 4.3-5 Graph of class and individuals of plan's ontologies

In the above graphs, the results of queries that applied on the selected ontology has been explained and show how many classes/concepts and individuals/instances each ontology has.

4.3.2 Triples (Subject, Object and Predicates)

Triples contains the subject, object and the predicate. Triples is like a sentence or the event which can give some kind of information about a resource. The following table 4.3-2 show the results of triples queries that are applied on all the selected ontologies. The total number of subject, object and predicates. And then explain the results using graphs and show which ontology has more number of triples (subject, object and predicates) in the ontologies.

Table 4.3-2 Results of triples (Subject, Object And Predicate)

Sr. #	Ontology title	Total Subject	Distinct Subject	Total Object	Distinct Object	Total Predicates	Distinct predicate	Total Triples
1	Collembola Anatomy Ontology	24619	6484	24619	7322	24619	23	24619
2	Sub-cellular Anatomy Ontology	38823	9120	38823	11549	38823	51	38823
3	Anatomic Ontology for Human Lung Maturation	7851	2070	7851	2467	7851	20	7851
4	Anatomic Entity Ontology	10992	2545	10992	3362	10992	20	10992
5	General formal ontology of biology	4322	1323	4322	1162	4322	24	4322
6	Planarian Anatomy and developmental Stage Ontology	35139	8223	35139	11212	35139	98	35139
7	Hymenoptera Anatomy Ontology	170500	41437	170500	43902	170500	24	170500
8	Chemical Information Ontology	19579	5480	19579	6130	19579	44	19579
9	NanoParticale Ontology	147697	33398	147697	32047	147697	30	147697
10	Alzheimer’s Disease Ontology	41830	10800	41830	13472	41830	24	41830
11	Epilepsy and Seizure Ontology	24626	7085	24626	7078	24626	26	24626
12	Neurodegenerative Disease Data Ontology	45539	12548	45539	14108	45539	52	45539
13	Flora Phenotype Ontology	1076452	293712	1076452	320415	1076452	41	1076452
14	Plant Diversity Ontology	227672	59564	227672	57266	227672	42	227672

4.3.2.1 Graphical representation of the above triples table:

The following graph 4.3-6 show he results of the triples on anatomy ontology. The results show that the SAO ontology has more number of subjects, object and predicates.

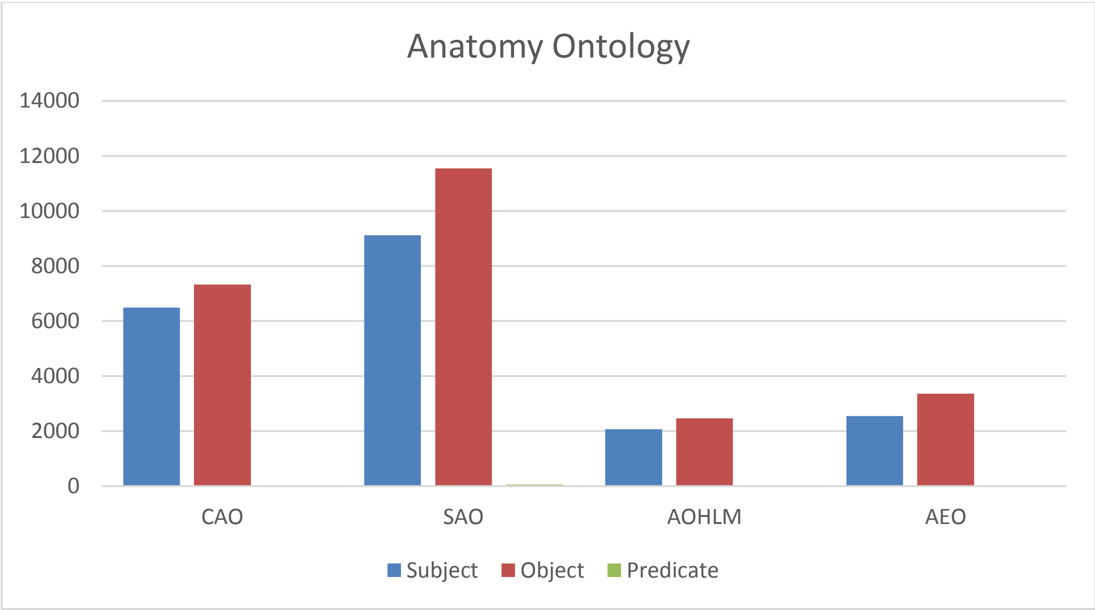


Figure 4.3-6 Graph of triples (Subject, object, predicates) of anatomy ontologies

The following graph 4.3-7 show he results of the triples on animal ontology. The results show that the HAO ontology has more number of subjects, object and predicates.

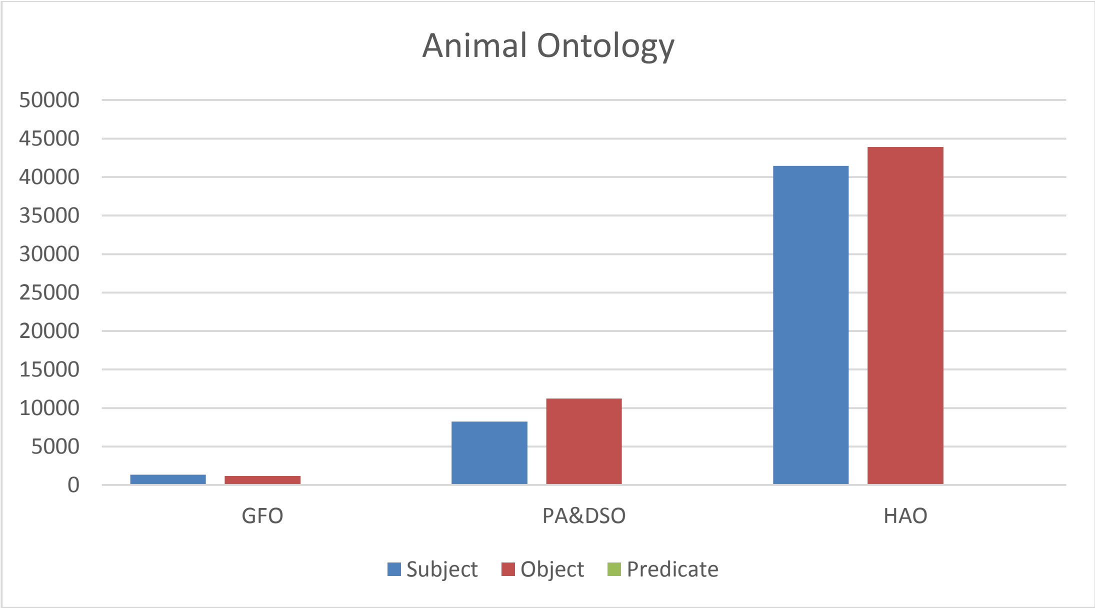


Figure 4.3-7 Graph of triples (Subject, object, predicates) of animal ontologies

The following graph 4.3-8 show he results of the triples on chemical ontology. The results show that the NPO ontology has more number of subjects, object and predicates.

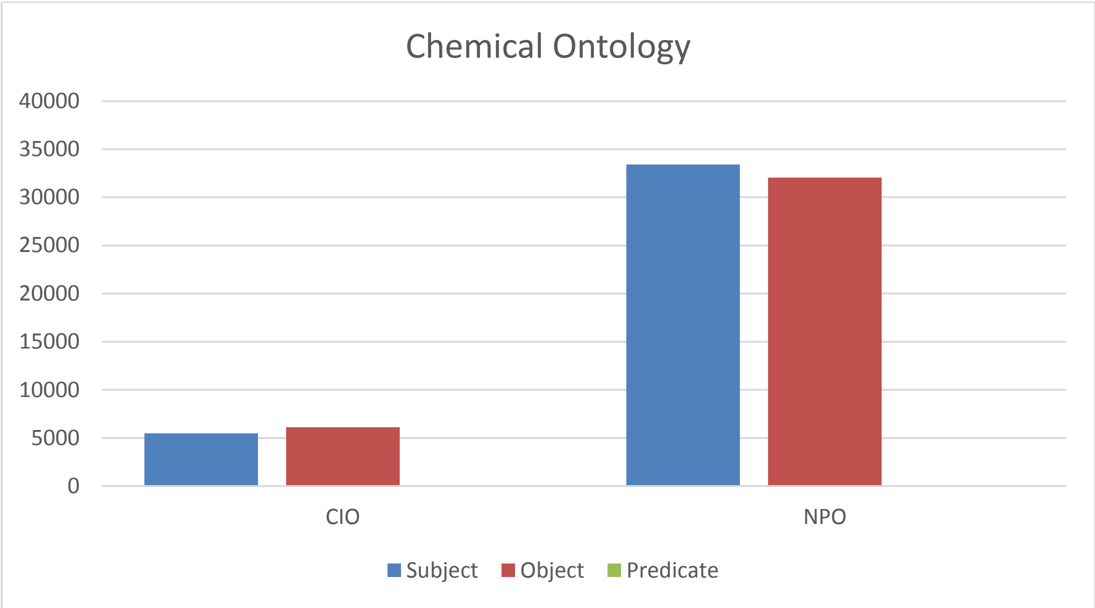


Figure 4.3-8 Graph of triples (Subject, object, predicates) of chemical ontologies

The following graph 4.3-9 show he results of the triples on neurological disease ontology. The results show that the NDDO ontology has more number of subjects, object and predicates.

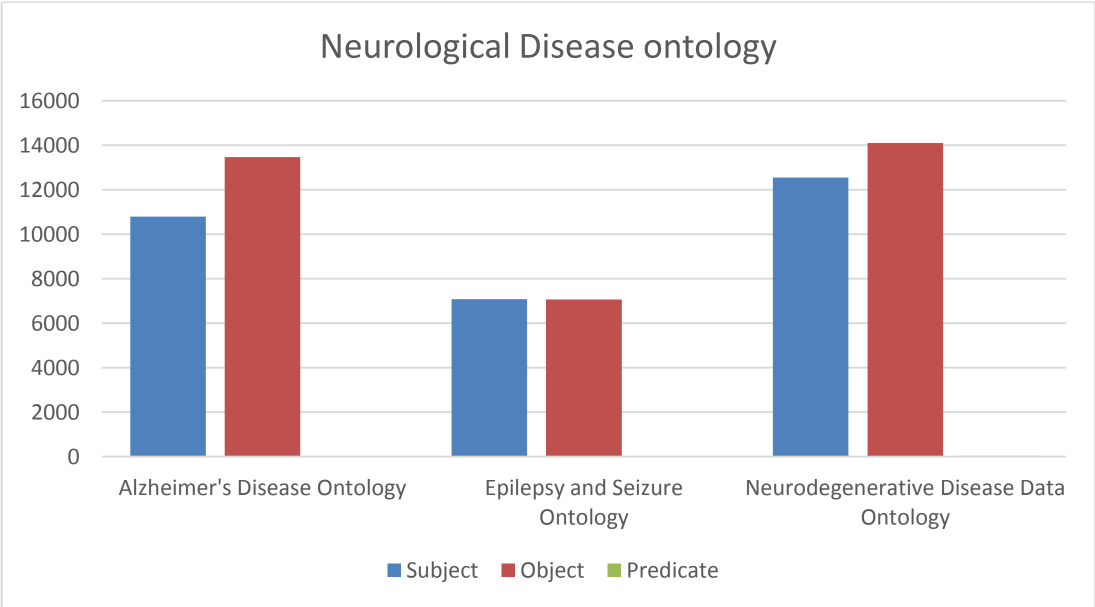


Figure 4.3-9 Graph of triples of neurological disease ontologies

The following graph 4.3-10 show he results of the triples on plant ontology. The results show that the FPO ontology has more number of subjects, object and predicates.

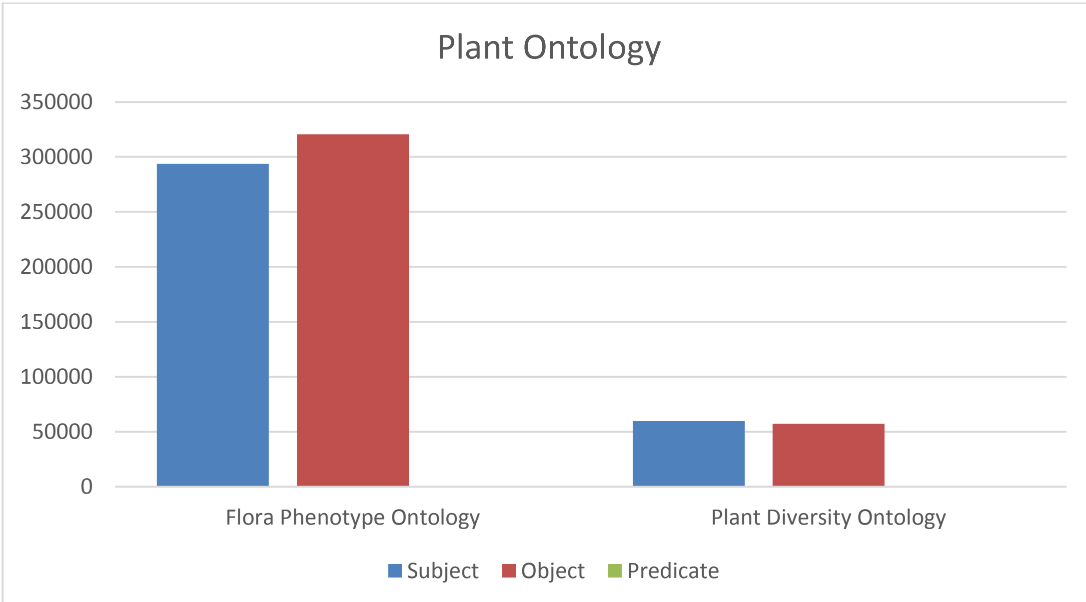


Figure 4.3-10 Graph of triples (Subject, object, predicates) of plants ontologies

In the above graphs, the results of queries that applied on the selected ontology has been explained and show how many triples (subjects, objects and predicates) each ontology has.

4.3.3 Relations

In ontologies there are two different types of relations, first is the relation between the classes (how each class interact with the other class.) second is the relation between the class and its instances. The following table 4.3-3 show the results of the relation queries that are applied on all the selected ontologies. The total number of relations between classes and equivalent classes are shown. And then explain the results using graphs and show which ontology has more number of relations in the ontologies.

Table 4.3-3 Relation in ontologies

Sr. #	Ontology title	Categories	No. of relations between classes	Equivalent classes relations	Total Relations
1	Collembola Anatomy Ontology	Human Anatomy	1579	1	1580
2	Subcellular Anatomy Ontology		915	4	919
3	Anatomic Ontology for Human Lung Maturation		547	0	547
4	Anatomic Entity Ontology		366	0	366
5	General formal ontology of biology	Animal Ontology	232	31	263
6	Planarian Anatomy and developmental Stage Ontology		789	51	840
7	Hymenoptera Anatomy Ontology		4820	1	4821
8	Chemical Information Ontology	Chemical Ontology	871	28	899
9	NanoParticale Ontology		3557	398	3955
10	Alzheimer's Disease Ontology	Neurological disease	2266	72	2338
11	Epilepsy and Seizure Ontology		1718	0	1718
12	Neurodegenerative Disease Data Ontology		493	2	495
13	Flora Phenotype Ontology	Plant Ontology	36886	23872	60785
14	Plant Diversity Ontology		816	0	816

4.3.3.1 Graphical representation of the above relations table

The following graph 4.3-11 show he results of the relations on anatomy ontology. The results show that the CAO ontology has more number of relations as compared to the other ontologies.

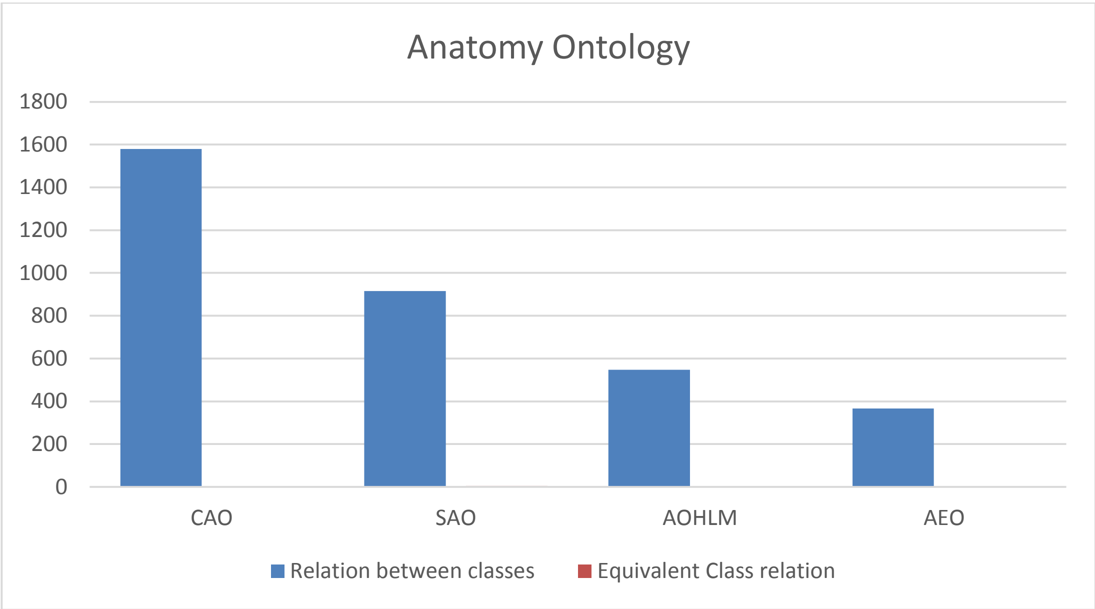


Figure 4.3-11 Graph of relations of anatomy ontologies

The following graph 4.3-12 show he results of the relations on animal ontology. The results show that the HAO ontology has more number of relations as compared to the other ontologies.

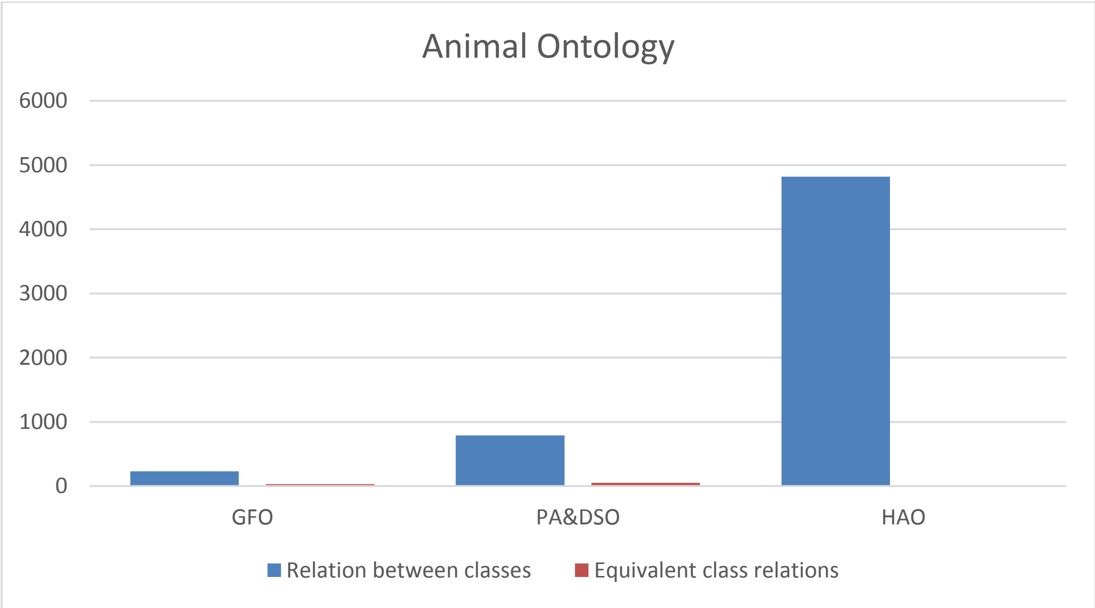


Figure 4.3-12 Graph of relations of animal ontologies

The following graph 4.3-13 show he results of the relations on chemical ontology. The results show that the NPO ontology has more number of relations as compared to the other ontologies.

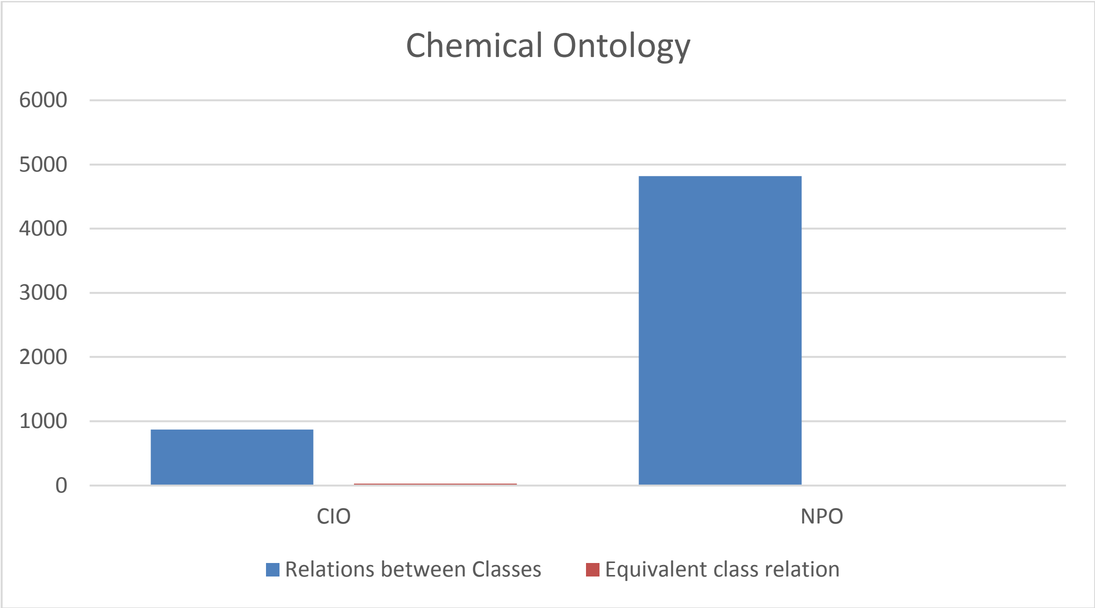


Figure 4.3-13 Graph of relations of chemical ontologies

The following graph 4.3-14 show he results of the relations on neurological disease ontology. The results show that the ADO ontology has more number of relations as compared to the other ontologies.

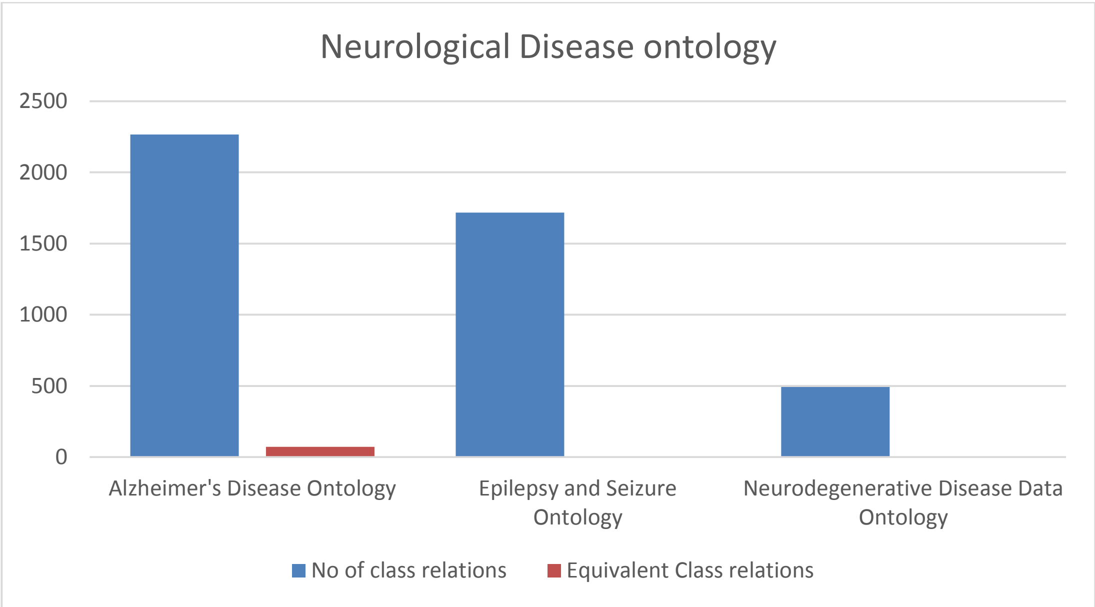


Figure 4.3-14 Graph of relation of neurological disease ontology

The following graph 4.3-15 show he results of the relations on plant ontology. The results show that the FPO ontology has more number of relations as compared to the other ontologies.

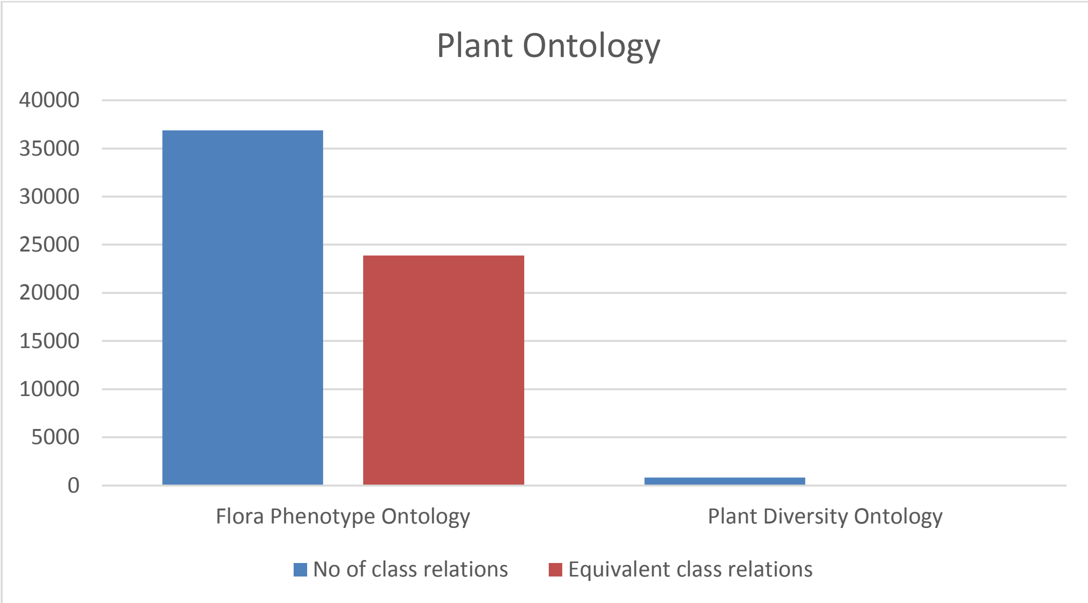


Figure 4.3-15 Graph of relation of plant ontologies

In the above graphs, the results of queries that applied on the selected ontology has been explained and show how many relations of classes each ontology has.

4.3.4 Properties:

Properties define the attributes and features of the concepts in the ontologies. Ontologies properties are the connection between the two or more instances. Properties are the relation between the instances or the objects. The properties that are used in the proposed criteria are Annotation properties, object properties, data properties, reflexive properties, function properties, inverse properties, asymmetric properties and symmetric properties. The following table 4.3-4 and 4.3-5 show the results of the properties queries that are applied on all the selected ontologies. The total number of properties are shown. And then explain the results using graphs and show which ontology has more number of properties in the ontologies.

Table 4.3-4 Properties of selected ontologies-1

Sr. #	Ontology Title	Annotation Property	Object Property	Data Property	Transitive Property
1	Collembola Anatomy Ontology	13	13	0	13
2	Subcellular Anatomy Ontology	34	36	0	2
3	Anatomic Ontology for Human Lung Maturation	19	0	0	0
4	Anatomic Entity Ontology	15	11	0	0
5	General formal ontology of biology	2	73	0	7
6	Planarian Anatomy and developmental Stage Ontology	81	131	0	19
7	Hymenoptera Anatomy Ontology	15	6	0	4
8	Chemical Information Ontology	40	69	0	17
9	NanoParticale Ontology	12	65	0	4
10	Alzheimer's Disease Ontology	17	12	0	1
11	Epilepsy and Seizure Ontology	7	28	0	0
12	Neurodegenerative Disease Data Ontology	35	64	0	2
13	Flora Phenotype Ontology	19	26	0	6
14	Plant Diversity Ontology	8	58	0	0

Table 4.3-5 Properties of selected ontologies-2

Sr. #	Ontology title	Inverse Properties	Functional Properties	Asymmetric Properties	Symmetric Properties	Reflexive Properties
1	Collembola Anatomy Ontology	1	0	11	2	0
2	Subcellular Anatomy Ontology	1	3	0	0	0
3	Anatomic Ontology for Human Lung Maturation	0	0	0	0	0
4	Anatomic Entity Ontology	0	0	0	0	0
5	General formal ontology of biology	0	7	0	0	0
6	Planarian Anatomy and developmental Stage Ontology	0	1	0	4	0
7	Hymenoptera Anatomy Ontology	0	0	0	0	4
8	Chemical Information Ontology	0	1	0	5	0
9	NanoParticale Ontology	0	1	0	0	0
10	Alzheimer's Disease Ontology	0	0	0	0	0
11	Epilepsy and Seizure Ontology	0	0	0	0	0
12	Neurodegenerative Disease Data Ontology	0	6	0	0	0
13	Flora Phenotype Ontology	0	0	0	0	2
14	Plant Diversity Ontology	0	0	0	0	0

4.3.4.1 Graphical representation of the above properties table:

The following graph 4.3-16 show he results of the properties of anatomy ontology. The results show that the SAO ontology has more number of properties as compared to the other ontologies.

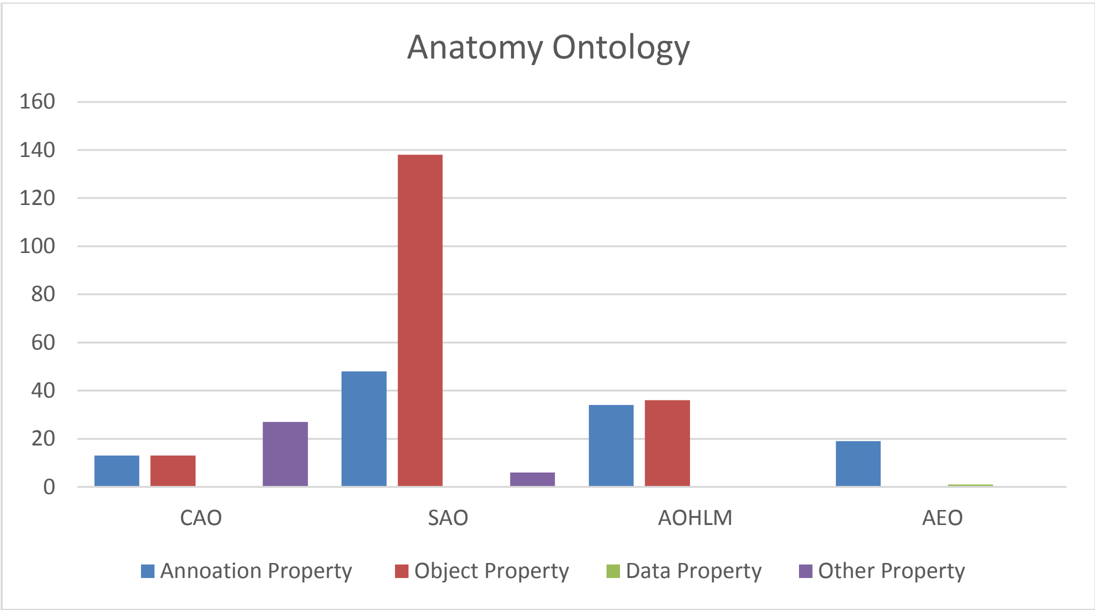


Figure 4.3-16 Graph of properties of anatomy ontologies

The following graph 4.3-17 show he results of the properties of animal ontology. The results show that the PA&DS ontology has more number of properties as compared to the other ontologies.

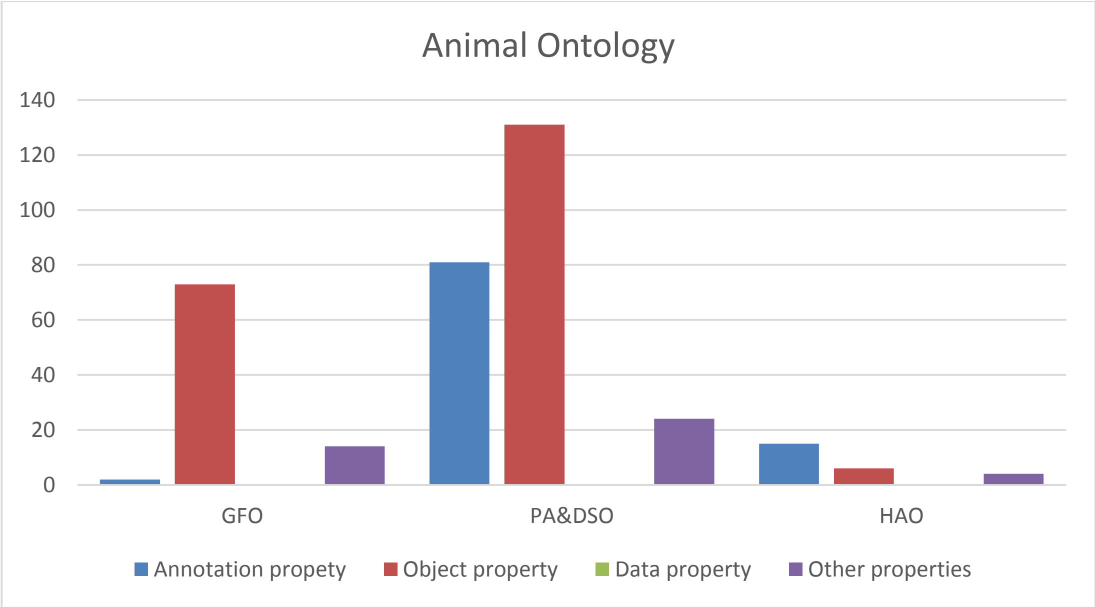


Figure 4.3-17 Graph of properties of animal ontologies

The following graph 4.3-18 show he results of the properties of chemical ontology. The results show that the NPO ontology has more number of properties as compared to the other ontologies.

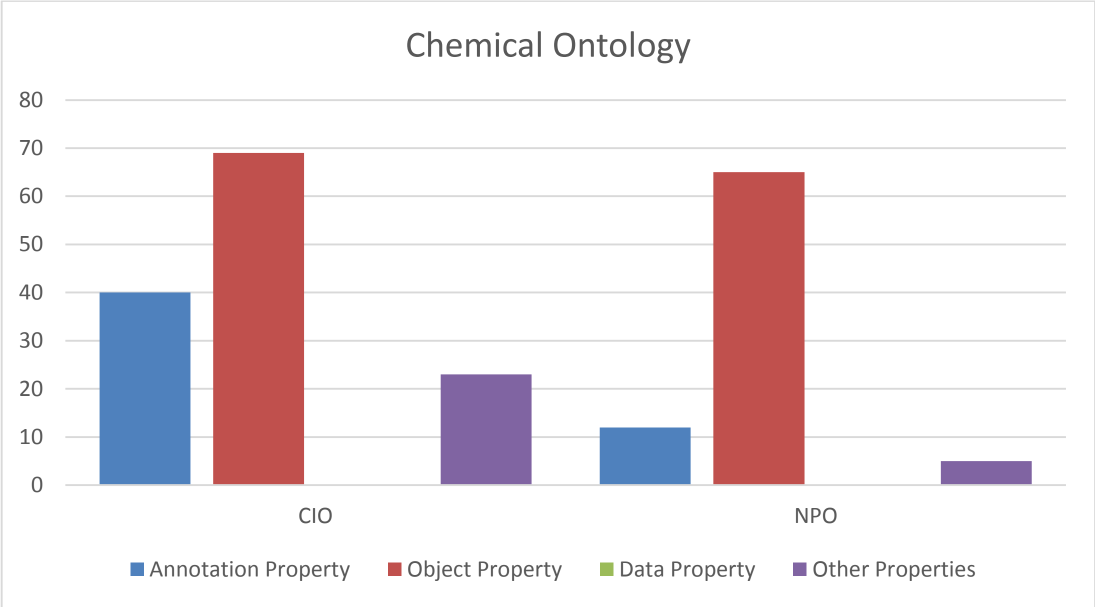


Figure 4.3-18 Graph of properties of chemical ontologies

The following graph 4.3-19 show he results of the properties of neurological ontology. The results show that the NDDO ontology has more number of properties as compared to the other ontologies.

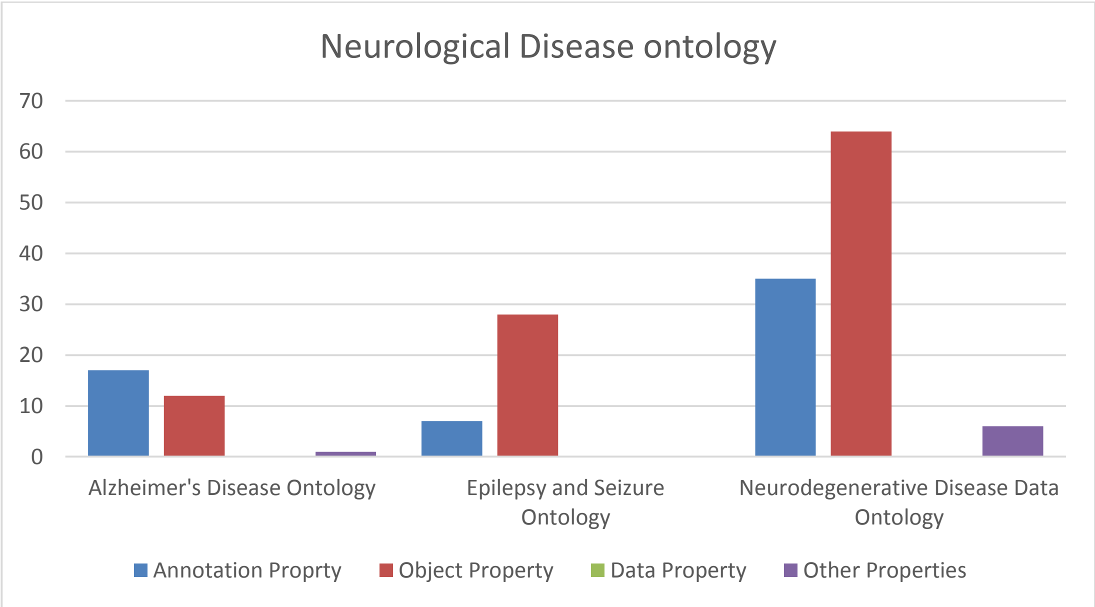


Figure 4.3-19 Graph of properties of neurological ontologies

The following graph 4.3-20 show he results of the properties of plant ontology. The results show that the PDO ontology has more number of properties as compared to the other ontologies.

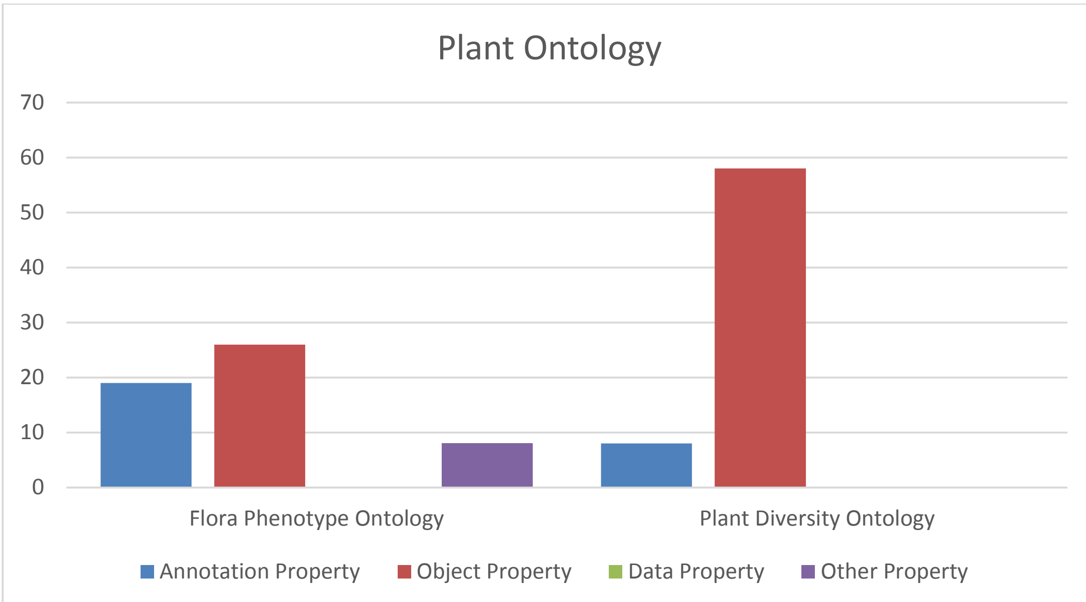


Figure 4.3-20 Graph of properties of plant ontologies

In the above graphs, the results of queries that applied on the selected ontology has been explained and show how many properties of classes each ontology has. These graph represents the quality of each ontology. All the selected ontologies are evaluated and their graph are shown above.

4.4 Comparison of same type of ontologies using proposed framework:

Another use of the proposed framework is that we can compare the ontologies to check which ontology is best in terms of quality. Comparison of ontology is necessary when we have to make a new ontology so we compare the new ontology with the existing ontology and evaluate that the new ontology is best as compared to the existing one. For this purpose, we import two ontologies from different portals. These ontologies belong to the same domain and both ontologies are make for the cell line descriptions. So we compare both ontologies according to our framework and compare the results of evaluation.

Cell line ontology CLO and MCCL are for the same domain ontology. We compare both ontology quality using the proposed framework. According to results the CLO is better in quality than MCCL because CLO has more classes, triples and properties but MCCL has more relation. The values of the class, triples, relations and properties and their graphical representation are following:

Table 4.4-1 Comparison of cell line ontologies

Sr #	Ontology	Total Classes/Individuals	Total Triples	Total Relations	Total Properties
1	Cell Line Ontology (CLO)	44874	140999	125545	117
2	Cell Line Ontology (MCCL)	5475	138088	135916	17

Following graph represent the class, individuals, triples, relation and properties of both ontologies and show the Cell line ontology (CLO) has more number of characteristics as compared to the MCCL ontology.

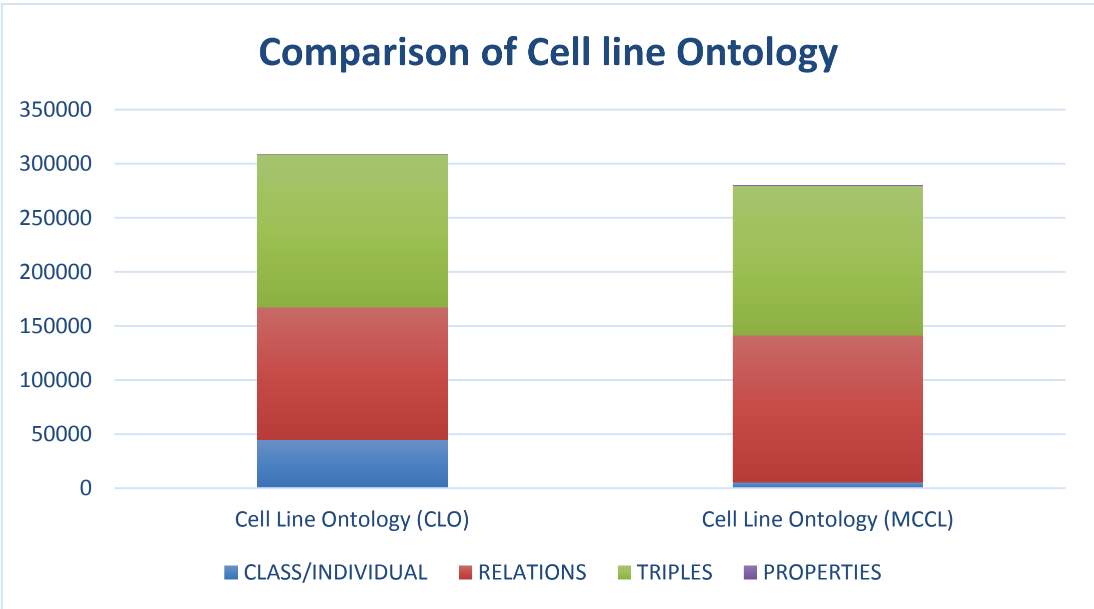


Figure 4.4-1 Graph of comparison of cell line ontologies

4.5 Comparison of Proposed framework with existing frameworks:

According to the literature, the frameworks that evaluate the ontology according to the structural characteristics are OntoQA, OntoBee, [57] and [60]. We have compare our proposed framework with these frameworks.

OntoQA evaluate the ontologies on the bases of the class, instances and the relations of the ontology. OntoQA cannot cover all the characteristics of ontology for quality evaluation of ontology. Also the OntoQA's framework only evaluate the ontology which have the owl format and evaluate only medical related ontologies. And the proposed framework can evaluate all the structural characteristics of ontologies and evaluate all domains related ontologies.

OntoBee evaluate the ontologies on the basis of the concept/class and the properties between the classes. Like OntoQA, this framework also cannot evaluate all the characteristics triples (subject, object, predicates) instances, relation and the other properties are missing. This framework only evaluates the medical related ontologies.

Khan's [60] framework for ontology evaluation can evaluate the classes, instances, triples (subject, object, predicate) and some properties. But some characteristics are missing for examples the relations between the classes and some properties like transitive property. This framework is only for the owl format related ontology and can evaluate only medical related ontology. As the proposed framework can evaluate almost all domain related ontologies and covered all the structural characteristics for the quality evaluation of the ontologies.

Tao's framework [57] can evaluate the RDF/XML formats ontology and evaluate the ontology on the bases of the class, instances, relation and some object related properties. But the triples (subject, object, predicates) and other properties are missing. As compared to the proposed framework, the proposed framework can evaluate the ontologies using all the structural characteristics and evaluate all the formats of the ontologies but the queries are different for all every format but the framework is same (Queries can very as the format is changed). Proposed framework can evaluate almost all the domains of the ontologies and they are explained in the result chapter.

Table 4.5-1 Comparison with related work

Ontologies	OntoQA	oQual	Ning's framework	Khan's Framework	OntoBee	Proposed framework	Reason
Dublin Core	-	Good Quality	-	-	Good Quality	Good Quality	All Characteristics are present
PROV-O	-	Bad Quality	-	-	Good Quality	Good Quality	All Characteristics are present
SKOS	-	Good Quality	-	-	Good Quality	Bad Quality	Properties are missing
GlycO	Bad Quality	-	-	-	-	Good Quality	All Characteristics are present
SWETO	Good Quality	Good Quality	-	-	-	Good Quality	All Characteristics are present
Ontology Biophysics	-	-	Good Quality	-	-	Good Quality	All Characteristics are present
Hymenoptera Anatomy Ontology	-	-	-	Good Quality	Good Quality	Good Quality	All Characteristics are present
Ontology for General Medical Science	-	-	-	Good Quality	Good Quality	Bad Quality	Properties are missing
Porifera Ontology	-	-	-	Good Quality	Bad Quality	Bad Quality	Properties and relationships between classes are missing
Uber Anatomy Ontology	-	-	-	Good Quality	Good Quality	Good Quality	All Characteristics are present

Following table can show the comparison of the frameworks.

Table 4.5-2 Comparison with existing frameworks

Structural Characteristics	OntoQA	OntoBee	[60]	[57]	Proposed Criteria
Subject			Y		Y
Object			Y		Y
Predicate			Y		Y
Concepts	Y	Y	Y	Y	Y
Instances	Y		Y	Y	Y
Relations	Y			Y	Y
Object property		Y	Y		Y
Annotation property		Y	Y		Y
Transitive Property					Y
Other Properties				Y	Y

The above graph 4.5-1 represent the comparison of the proposed methodology with the existing frameworks and shows that the proposed framework can evaluate all the structural characteristics.

Chapter 5

Conclusion and Future work

CHAPTER 5: CONCLUSION AND FUTURE WORK

5.1 Conclusion:

There are many ontology web portals and thousands of ontologies was made on different domains. So to find out which ontology is better and which ontology can solve the required problems ontology evaluation is very important. The main focus of ontology evaluation is to estimating the quality of ontology. Ontology evaluation is the most important and complex part of ontology engineering process because it involves in the different levels of ontology formation that are evaluation and the reuse. Our proposed framework can evaluate the quality of ontology using the structural characteristic that are concept/class, individuals/instances, relations between classes, triples (subject, predicate, object), properties.

Our proposed framework used to evaluate the ontologies and also used for the comparison of ontologies and tell which ontology is best in terms of quality and structure. We applied the SPARQL queries on the selected different domains related ontologies and explain the results in the tables and also the form of graphs. Our proposed framework can evaluate all the formats of ontologies but in this research we only use owl format because owl is the most used format of ontology. For other formats the proposed framework is same but the queries that are used is different according to the format. For evaluation we use protégé and SPARQL queries.

The proposed framework is used for all domains related ontologies. For our proposed framework we select four human anatomy ontologies, three animal ontologies, two chemicals ontologies, three neurological ontologies and two plant ontologies. We applied all the queries on every selected ontology and explain the results. we also compare the quality or two same type of ontology and explain which ontology is best in terms of quality. In this framework we try to evaluate all the possible different domains related ontologies not just medical ontologies.

The limitation of the proposed framework is that it can only evaluate the structural characteristics and evaluate the ontology on the basis of the quality and ignore the quantitative aspects.

The advantage of the framework is that it can evaluate all the domains ontologies not just medical ontologies and this framework can also use for the comparison of ontologies. This framework can use for the evaluation of all different type of formats of ontology but the queries are different for each format. This framework covers all the structural characteristics. And helps the researcher to find the best quality ontology.

5.2 Future work

As the proposed framework's evaluation results are very precise and the comparison of ontologies give information about the improvement and quality of the ontologies. The proposed framework can only evaluate the quality of ontology. In future quantitative evaluation criteria should be proposed for evaluation of ontologies. And also make a web portal for the evaluation of the ontologies. In the proposed framework, when we compare two ontologies it can only give a numerical number of characteristics difference in further the comparison can also tell the same and different characteristics of each ontology.

REFERENCES

[1]. Ashraf, Jamshaid, Omar K. Hussain, Farookh Khadeer Hussain, and Elizabeth J. Chang. Measuring and Analysing the Use of Ontologies: A Semantic Framework for Measuring Ontology Usage. Vol. 767. Springer, 2018.

[2]. Kharbat, Faten, and Haya El-Ghalayini. "Building ontology from knowledge base systems." In Data Mining in Medical and Biological Research. IntechOpen, 2008.

[3]. Gruber, Tom. "Ontology." (2018).

[4]. Hofweber, Thomas. "Ontology and the Ambitions of Metaphysics." (2018): 289-291.

[5]. Amith, Muhammad, Zhe He, Jiang Bian, Juan Antonio Lossio-Ventura, and Cui Tao. "Assessing the practice of biomedical ontology evaluation: Gaps and opportunities." Journal of biomedical informatics 80 (2018): 1-13.

[6]. Eisenberg, Ian W., Patrick G. Bissett, A. Zeynep Enkavi, Jamie Li, David P. MacKinnon, Lisa A. Marsch, and Russell A. Poldrack. "Uncovering the structure of self-regulation through data-driven ontology discovery." Nature communications 10, no. 1 (2019): 2319.

[7]. Dou, Dejing, Hao Wang, and Haishan Liu. "Semantic data mining: A survey of ontology-based approaches." In Proceedings of the 2015 IEEE 9th international conference on semantic computing (IEEE ICSC 2015), pp. 244-251. IEEE, 2015.

[8]. Kless, Daniel, Simon Milton, Edmund Kazmierczak, and Jutta Lindenthal. "Thesaurus and ontology structure: Formal and pragmatic differences and similarities." Journal of the Association for information science and technology 66, no. 7 (2015): 1348-1366.

[9]. Groß, Anika, Cédric Pruski, and Erhard Rahm. "Evolution of biomedical ontologies and mappings: Overview of recent approaches." Computational and structural biotechnology journal 14 (2016): 333-340.

[10]. Amith, Muhammad, Frank J. Manion, Marcelline R. Harris, Yaoyun Zhang, Hua Xu, and Cui Tao. "Expressing biomedical ontologies in natural language for expert evaluation." Studies in health technology and informatics 245 (2017): 838

[11]. Konopka, Bogumil M. "Biomedical ontologies—A review." Biocybernetics and Biomedical Engineering 35, no. 2 (2015): 75-86.

[12]. Fleuren, Wilco WM, and Wynand Alkema. "Application of text mining in the biomedical domain." Methods 74 (2015): 97-106.

[13]. Amith, Muhamamd, and Cui Tao. "A web application towards semiotic-based evaluation of biomedical ontologies." In International Workshop on Biomedical Data Mining, Modeling, and Semantic Integration: A Promising Approach to Solving Unmet Medical Needs, BDM2I 2015-co-located with the 14th International Semantic Web Conference, ISWC 2015. CEUR-WS, 2015.

[14]. Baliyan, Niyati, and Ankita Verma. "Recent Advances in the Evaluation of Ontology Quality." In Semantic Web Science and Real-World Applications, pp. 326-348. IGI Global, 2019.

[15]. Zhong, Zhaoman, Zongtian Liu, Wei Liu, Yan Guan, and Jianfang Shan. "Event ontology and its evaluation." journal of Information &Computational Science 7, no. 1 (2010): 95-101.

[16]. Sfar, Hela, Anja Habacha Chaibi, Amel Bouzeghoub, and Henda Ben Ghezala. "Gold standard based evaluation of ontology learning techniques." In Proceedings of the 31st Annual ACM Symposium on Applied Computing, pp. 339-346. ACM, 2016.

[17]. Brank, J., Mladenic, D. and Grobelnik, M., 2006, May. Gold standard based ontology evaluation using instance assignment. In Workshop on Evaluation of Ontologies for the Web, EON.

[18]. Singh, Satyaveer, and Mahendra Singh Aswal. "Ontology Learning Procedures Based on Web Mining Techniques." Available at SSRN 3382660 (2019).

[19]. Thuan, Nguyen Hoang, Pedro Antunes, and David Johnstone. "A decision tool for business process crowdsourcing: ontology, design, and evaluation." Group Decision and Negotiation 27, no. 2 (2018): 285-312.

[20]. Jain, Sarika, and Valerie Meyer. "Evaluation and refinement of emergency situation ontology." Int J Inform Educ Technol 8, no. 10 (2018): 713-719.

[21]. Hazman, Maryam, Samhaa R. El-Beltagy, and Ahmed Rafea. "A survey of ontology learning approaches." International Journal of Computer Applications 22, no. 9 (2011): 36-43.

[22]. Jain, Sarika, and Valerie Meyer. "Evaluation and refinement of emergency situation ontology." Int J Inform Educ Technol 8, no. 10 (2018): 713-719.

[23]. Noh, Heeyong, Ju-Hwan Seo, Hyoung Sun Yoo, and Sungjoo Lee. "How to improve a technology evaluation model: A data-driven approach." Technovation 72 (2018): 1-12.

[24]. Brewster, Christopher, Harith Alani, Srinandan Dasmahapatra, and Yorick Wilks. "Data driven ontology evaluation." (2004).

[25]. Malik, Zeeshan Haider. "Usability evaluation of ontology engineering tools." In 2017 Computing Conference, pp. 576-584. IEEE, 2017.

[26]. Luo, Lingyun, José LV Mejino Jr, and Guo-Qiang Zhang. "An analysis of FMA using structural self-bisimilarity." Journal of biomedical informatics 46, no. 3 (2013): 497-505.

[27]. Agrawal, Ankur, and Gai Elhanan. "Contrasting lexical similarity and formal definitions in SNOMED CT: Consistency and implications." Journal of biomedical informatics 47 (2014): 192-198.

[28]. Rector, Alan, and Luigi Iannone. "Lexically suggest, logically define: Quality assurance of the use of qualifiers and expected results of post-coordination in SNOMED CT." Journal of biomedical informatics 45, no. 2 (2012): 199-209.

[29]. Bodenreider, Olivier. "Identifying Missing Hierarchical Relations in SNOMED CT from Logical Definitions Based on the Lexical Features of Concept Names." ICBO/BioCreative 2016 (2016).

[30]. Patel, Chintan, Kaustubh Supekar, Yugyung Lee, and E. K. Park. "OntoKhoj: a semantic web portal for ontology searching, ranking and classification." In Proceedings of the 5th ACM international workshop on Web information and data management, pp. 58-61. ACM, 2003.

[31]. Ding, Li, Tim Finin, Anupam Joshi, Rong Pan, R. Scott Cost, Yun Peng, Pavan Reddivari, Vishal Doshi, and Joel Sachs. "Swoogle: a search and metadata engine for the semantic web." In Proceedings of the thirteenth ACM international conference on Information and knowledge management, pp. 652-659. ACM, 2004.

[32]. TALEBPOUR, M., MD SYKORA, and T. JACKSON. "On-tology selection for reuse: Will it ever get easier." In IN: Proceedings of the 10th International Joint Conference on Knowledge Discovery, Knowledge Engineer-ing and Knowledge Management (KEOD 2018), Seville, Spain, pp. 108-116. Science and Technology Publications, 2018.

[33]. Oliveira, Daniela, Anila Sahar Butt, Armin Haller, Dietrich Rebholz-Schuhmann, and Ratnesh Sahay. "Where to search top-K biomedical ontologies?" Briefings in bioinformatics 20, no. 4 (2018): 1477-1491.

[34]. Lozano-Tello, Adolfo, and Asunción Gómez-Pérez. "Ontometric: A method to choose the appropriate ontology." Journal of Database Management (JDM) 15, no. 2 (2004): 1-18.

[35]. Fonou-Dombeu, Jean Vincent, and Serestina Viriri. "OntoMetrics Evaluation of Quality of e-Government Ontologies." In International Conference on Electronic Government and the Information Systems Perspective, pp. 189-203. Springer, Cham, 2019.

[36]. Jain, Sarika, and Valerie Meyer. "Evaluation and refinement of emergency situation ontology." Int J Inform Educ Technol 8, no. 10 (2018): 713-719.

[37]. Ermolayev, Vadim. "OntoElecting Requirements for Domain Ontologies." Enterprise Modelling and Information Systems Architectures (EMISAJ) 13 (2018): 86-109.

[38]. Ma, Xiaogang, Linyun Fu, Patrick West, and Peter Fox. "Ontology Usability Scale: Context-aware Metrics for the Effectiveness, Efficiency and Satisfaction of Ontology Uses." Data Science Journal 17 (2018).

[39]. Brooke, John. "SUS-A quick and dirty usability scale." Usability evaluation in industry 189, no. 194 (1996): 4-7.

[40]. Alani, Harith, Christopher Brewster, and Nigel Shadbolt. "Ranking ontologies with AKTiveRank." In International Semantic Web Conference, pp. 1-15. Springer, Berlin, Heidelberg, 2006.

[41]. Iaksch, Jaqueline Sebastiany, and Milton Borsato. "Method for digital evaluation of existing production systems adequacy to changes in product engineering in the context of the automotive industry." Advanced Engineering Informatics 42 (2019): 100942.

[42]. de Oliveira Rodrigues, Cleyton Mário, Frederico Luiz Gonçalves de Freitas, and Ryan Ribeiro de Azevedo. "An Ontology Analysis Implementation in Constraint Logic Programming." In 2015 IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology (WI-IAT), vol. 1, pp. 317-320. IEEE, 2015.

[43]. Ashraf, Jamshaid, Omar K. Hussain, Farookh Khadeer Hussain, and Elizabeth J. Chang. "Evaluation of U Ontology." In Measuring and Analysing the Use of Ontologies, pp. 243-268. Springer, Cham, 2018.

[44]. Guarino, N., and C. A. Welty. "An Overview of Ontoclean, International Handbooks on Information Systems, 2009, Handbook on Ontologies, Part 2, S. Staab, D. Rudi Studer." (2009): 201-220.

[45]. Tartir, Samir, I. Budak Arpinar, Michael Moore, Amit P. Sheth, and Boanerges Aleman-Meza. "OntoQA: Metric-based ontology quality analysis." (2005).

[46]. Dharmawan, Mochamad Tri, Husni Tcja Sukmana, Luh Kesuma Wardhani, Yuditha Ichsani, and Imam Subchi. "The Ontology of IT Service Management by Using ITILv. 3 Framework: A Case Study for Incident Management." In 2018 Third International Conference on Informatics and Computing (ICIC), pp. 1-5. IEEE, 2018.

[47]. McDaniel, Melinda, Veda C. Storey, and Vijayan Sugumaran. "Assessing the quality of domain ontologies: Metrics and an automated ranking system." Data & Knowledge Engineering 115 (2018): 32-47.

[48]. García-Peñalvo, Francisco José, Juan García, and Roberto Therón. "Analysis of the OWL ontologies: A survey." Scientific Research and Essays 6, no. 20 (2011): 4318-4329.

[49]. Dividino, Renata, and Daniel Sonntag. "Controlled ontology evolution through semiotic-based ontology evaluation." In Proceedings of International Workshop on Ontology Dynamics (IWOD 2008), ISWC 2008 Conference, pp. 1-14. 2008.

[50]. Djedidi, Rim, and Marie-Aude Aufaure. "ONTO-EVO A L an ontology evolution approach guided by pattern modeling and quality evaluation." In International Symposium on Foundations of Information and Knowledge Systems, pp. 286-305. Springer, Berlin, Heidelberg, 2010.

[51]. Khattak, Asad Masood, Rabia Batool, Zeeshan Pervez, Adil Mehmood Khan, and Sungyoung Lee. "Ontology Evolution and Challenges." J. Inf. Sci. Eng. 29, no. 5 (2013): 851-871.

[52]. Good, Benjamin M., Gavin Ha, Chi K. Ho, and Mark D. Wilkinson. "OntoLoki: an automatic, instance-based method for the evaluation of biological ontologies on the Semantic Web." arXiv preprint arXiv:1502.06025 (2015).

[53]. Corcoglioniti, Francesco, Marco Rospocher, and Alessio Palmero Aprosio. "Frame-based ontology population with PIKES." IEEE Transactions on Knowledge and Data Engineering 28, no. 12 (2016): 3261-3275.

[54]. Mizoguchi, Riichiro, and Kouji Kozaki. "Ontology engineering environments." In Handbook on Ontologies, pp. 315-336. Springer, Berlin, Heidelberg, 2009.

[55]. Hammar, Karl. "Quality of Content Ontology Design Patterns." (2016): 51-71.

[56]. Gangemi, Aldo, Carola Catenacci, Massimiliano Ciaramita, and Jos Lehmann. "A theoretical framework for ontology evaluation and validation." In SWAP, vol. 166, p. 16. 2005.

[57]. Tao, Ming, Kaoru Ota, and Mianxiong Dong. "Ontology-based data semantic management and application in IoT-and cloud-enabled smart homes." Future generation computer systems 76 (2017): 528-539.

[58]. Ning, Huang, and Diao Shihan. "Structure-based ontology evaluation." In 2006 IEEE International Conference on e-Business Engineering (ICEBE'06), pp. 132-137. IEEE, 2006.

[59]. Xiang, Zuoshuang, Chris Mungall, Alan Ruttenberg, and Yongqun He. "Ontobee: A linked data server and browser for ontology terms." In ICBO. 2011.

[60]. Khan, Samiullah, Usman Qamar, and Abdul Wahab Muzaffar. "A Framework for Evaluation of OWL Biomedical Ontologies Based on Properties Coverage." In 2015 13th International Conference on Frontiers of Information Technology (FIT), pp. 59-64. IEEE, 2015.

[61]. Parsia, Bijan, and Aditya Kalyanpur. "Annotating OWL Ontologies." In SemAnnot@ ISWC. 2004.

[62]. Martínez-Romero, Marcos, Clement Jonquet, Martin J. O'connor, John Graybeal, Alejandro Pazos, and Mark A. Musen. "NCBO Ontology Recommender 2.0: an enhanced approach for biomedical ontology recommendation." Journal of biomedical semantics 8, no. 1 (2017): 21.

[63]. Tchechmedjiev, Andon, Amine Abdaoui, Vincent Emonet, Soumia Melzi, Jitendra Jonnagaddala, and Clement Jonquet. "Enhanced functionalities for annotating and indexing clinical text with the NCBO Annotator+." Bioinformatics 34, no. 11 (2018): 1962-1965.

[64]. Smith, Barry, Michael Ashburner, Cornelius Rosse, Jonathan Bard, William Bug, Werner Ceusters, Louis J. Goldberg et al. "The OBO Foundry: coordinated evolution of ontologies to support biomedical data integration." Nature biotechnology 25, no. 11 (2007): 1251.

[65]. Glimm, Birte, Ian Horrocks, Boris Motik, Rob Shearer, and Giorgos Stoilos. "A novel approach to ontology classification." Web Semantics: Science, Services and Agents on the World Wide Web 14 (2012): 84-101.

[66]. Van Rees, Reinout. "Clarity in the usage of the terms ontology, taxonomy and classification." CIB REPORT 284, no. 432 (2003): 1-8.

[67]. Martin, Philippe A., and Jérémy Bénard. "Categorizing or generating relation types and organizing ontology design patterns." In 2017 Federated Conference on Computer Science and Information Systems (FedCSIS), pp. 1109-1117. IEEE, 2017.

[68]. Lorge, Freddy, Matthew A. Pantland, and Tom Rojahn. "Building an ontology by transforming complex triples." U.S. Patent 9,298,817, issued March 29, 2016.

[69]. Liu, Xiaoqiang, Zhenbo Guo, Kaixi Wang, and Wenxu Jiang. "Study and Development of Question Answering System based on Ontology Query." In 2016 International Conference on Intelligent Control and Computer Application (ICCA 2016). Atlantis Press, 2016.

[70]. Bytyçi, Eliot, Lule Ahmedi, and Francesca A. Lisi. "Enrichment of Association Rules through Exploitation of Ontology Properties–Healthcare Case Study." Procedia computer science 113 (2017): 360-367.