International Journal of Computers and Applications

ISSN: 1206-212X (Print) 1925-7074 (Online) Journal homepage: http://www.tandfonline.com/loi/tjca20

Ontologies as a semantic model in IoT

Sanju Mishra & Sarika Jain

To cite this article: Sanju Mishra & Sarika Jain (2018): Ontologies as a semantic model in IoT, International Journal of Computers and Applications, DOI: 10.1080/1206212X.2018.1504461

To link to this article: https://doi.org/10.1080/1206212X.2018.1504461

Published online: 06 Aug 2018.

INTERNATIONAL JOURNAL OF COMPUTERS AND APPLICATIONS
https://doi.org/10.1080/1206212X.2018.1504461

Taylor & Francis
Taylor & Francis Group

Ontologies as a semantic model in IoT

Sanju Mishra and Sarika Jain

Department of Computer Applications, National Institute of Technology, Kurukshetra, India

ABSTRACT

The world is witnessing an increasing use of IoT-based devices to collect sensor data in order to perceive the real world and generate abstractions. This data is highly heterogeneous in nature as it is obtained from various domains utilizing different representation schemes. Semantic approaches come as a rescue to this interoperability problem incurred because of heterogeneous sensor data from IoT devices. The data thus obtained should be represented in form of ontologies which are considered as the cornerstone of the Semantic Web for knowledge sharing, information extraction, information integration and many more. The content and the quality of the ontologies should be analyzed by evaluating them to ensure that the ontology is well designed, structured, and contains all essential concepts and relationships between them for efficient reasoning. This paper focuses on the evaluation of ontologies and, as a case study, evaluates a Military Resource Ontology (MRO) by using evaluation tools such as OntoMetric, OOPs!, ONTOCOM, based on evaluation approaches, aspects and criteria. These tools detect errors by diagnosing various metrics and pitfalls. Evaluation methods are grouped in two phases: verification and validation. In this paper, 'QueryOnto' tool is introduced to verify and validate the MRO by searching, query/answering, and visualizing.

ARTICLE HISTORY
Received 29 April 2018
Accepted 20 July 2018

KEYWORDS
Internet of Things; Ontology Evaluation; QueryOnto; competency questions; Military Resource Ontology

1. Introduction

Because of significant attention from the research community, The Internet of Things (IoT) technology has been demonstrated to be a viable leading to an increased number of IoT applications. The primary goal of IoT is to interconnect devices and to collect data from them to create situational awareness and enable machines and humans better understand the situation or context hence facilitating better decision making and responses. IoT is being adapted in a large number of domains such as weather monitoring, water management, energy management, education, traffic control, retail, healthcare etc [1,2]. The IoT application space is quite heterogeneous and diverse due to which smart integration of data, applications and services has become a challenge in today's world. The current approaches and technologies to IoT adaptation may not go a long way because of the ever-growing number of IoT devices and their diversity in representing data. Though web has a lot of information and is a convenient platform for integrating things, the machine cannot understand the intended meaning. Web 3.0 or simply semantic web further improves its capacity and capability of understanding the data coming from diverse IoT devices. The semantic web is the web of the future which helps machines understand the web page and makes life easier by facilitating the interoperability of various IoT devices. Semantic Web technologies are extensively employed to build interoperable IoT applications. Semantic approaches facilitate enhanced searches for data from voluminous and complex data sets from cloud [3]. All this is made possible because of the availability of common formats and metadata in the form of ontology. Ontologies provide a machine-understandable description of entities, relationships, and individuals. An ontology is a fundamental data structure for conceptualizing knowledge. Ontology can represent shared domain knowledge and enable semantic interoperability. It is used to capture the semantics of data in growing Semantic Web and treated as a backbone of semantic web applications and knowledge-based systems. Design and development of an ontology is a complex and ambiguous task, which takes a lot of effort and needs to be constantly reviewed to judge if concepts and relationships included are correct [4].

Generally, ontology keeps sufficient knowledge for achieving completeness to solve major problems, but evaluation is important to describe the ontology qualities and suitabilities for use. The Ontological model builds upon and extends the existing efforts in modeling and standardizing the IoT domain concepts and aims to

CONTACT Sanju Mishra sanju.tiwari.2007@gmail.com

capture most of the important relationships among those concepts. It is must to evaluate ontologies for ensuring the correctness and completeness of developing ontologies. The structure and strength of ontologies are the main aspects to serve for the intended purpose. This can be achieved by the constant evaluation of ontologies in the development process and before reuse or release of ontologies. Ontology Evaluation (OE) is a challenging task and critical to the improvement and adoption of ontologies due to the fact that they are semantically oriented. Semantics always involves ambiguity. This paper aims to underline the significance of OE and to present a verification and validation method used during the ontology construction. Evaluation of ontology methods is based on two major concepts such as verification and validation methods to assure the ontology structure and examine the application of ontology in the real world. Various qualitative and quantitative methods exist, such as Ontometric, OOPs, OntoQA, and ONTOCOM. These methods investigate different characteristics of ontology. Ontologies play significant roles for knowledge modeling and management in military applications. Various military applications that use an ontology to execute effective military affairs have been increasing. Several ontologies have been designed for different military purposes like command and control [5,6], situation awareness [7,8], military coalition [9] and intrusion detection and prevention [10]. A Military Resource Ontology (MRO) had been designed in [11] to enable an automatic and effective response to all kinds of military information. The MRO maximizes the collection of military information at one place, but its best results can only be guaranteed if high-quality ontology is provided. The effectiveness of the ontological knowledge relies on the quality of the ontology.

There are different evaluation methods and approaches for OE, but still, there is a large gap to cover for vigorous semantic web ontologies. This paper aims to enhance the theoretical knowledge of ontology engineering applications and to facilitate guidance for OE based on several approaches, criteria and methods. The first task of the evaluator is, therefore, to choose the criteria relevant for the given evaluation and then to choose the proper evaluation methods to assess how well the ontology meets with the user requirements. Some researchers have proposed metrics such as richness, reusability, completeness, interoperability, which significantly meets user requirements. Some researchers evaluated ontology at certain levels rather than the complete ontology. These levels are considered as evaluation aspects such as syntax, structure, semantics, context, vocabulary, and representation and discussed in Section 2. The MRO is evaluated by using OntoMetric tool based on several metrics (Class, Schema, Base, Instance, and Graph) and OOPs online tool based on different criteria (Completeness, Correctness, Consistency, Conciseness, Clarity).

In this paper, existing OE approaches, aspects and criteria are discussed in Section 2. The MRO that is developed in [11] has been evaluated in Section 3 of this paper. The evaluation has been done based on several criteria and existing tools. After analyzing the values of various parameters on OntoMetric, OOPs, ONTOCOM and QueryOnto tool, the results are framed in Section 3.3. At last, in Section 4 relevant conclusions have been drawn.

2. Background

OE is an emerging field that has various approaches, aspects, criteria, and tools. An introduction of existing approaches has been discussed in Section 2.1. Various aspects of OE are discussed in Section 2.2. There are several criteria discussed in Section 2.3. for verification and validation of ontology. Section 2.4. discusses the existing tools for measuring the metrics and criteria.

2.1. Existing approaches of OE

Several researchers have presented different approaches for OE with respect to scopes, domains, and ontologies purposes. There is a need to take a holistic view at OE to gain a better understanding of the problem. This section summarizes the available OE approaches [12].

- *Logical or rule-based:* In this approach, rules are used for quality evaluation and validation of ontology. These rules are designed into ontology language and help to identify conflicts. For example – 'owl: disjointWith' depicts that two classes cannot have a common individual, such as *Man* and *Woman*, both will be disjoint classes. So these types of conflicts are easily detected by this approach.
- *Evolution-based:* This approach is used to track the relevant characteristics of ontologies that change over time. Ontologies have declarative nature and need to change time to time. It is always required to add more knowledge into corresponding domains and also add to ontologies correctly. The changes in ontology occur due to three causes: changes in the domain, in conceptualization, and in the explicit specification.
- *Metric-based or feature-based*: Metric-based techniques offer a quantitative aspect of ontology quality. These techniques examine through the ontology to assemble different types of statistics about the knowledge contained in the ontology. Various tools, such as OntoMetric, OntoQA, Ontoclean, AKTiveRank, and ODEval, have been implemented based on

this approach. Burton-Jones [13] and Gangemi [14] proposed several ontology quality metrics. Several criteria are represented by Verendic [15] for analysis OE criteria.

- *Application-based*: In this approach [16], ontology is used in an application for evaluating the results. This approach is very effective to analyze the capabilities of the designed ontology and effective to reach its goals, e.g. knowledge management and decision support. But this is not capable to assess the quality of the design and content of the ontology.
- *Data-driven*: This approach compares the ontology with a corpus by performing concept extraction on the corpus and counting the number of concepts that overlap between the corpus and ontology. The ontology is criticized, if the concepts used in the ontology are not present in the corpus. This approach is not appropriate for correctness, clarity, and usability of ontology. While it is more suitable for measuring coverage of the ontology.
- *Evaluation by humans:* This approach uses a set of existing criteria to evaluate the ontology. To analyze the suitability of ontology, Lozano-Tello and Gómez-Pérez [17] proposed a method OntoMetric, this method is an example of a human-based approach. The computations are based on the five main dimensions of languages, tools, content, cost, and methodology.
- *The Gold standard*: This approach measures the ontology to high level and gold standard that can be ontology itself. Gold standard is considered as a reference-based evaluation of ontologies [6] where a new ontology can be compared with the gold ontology, using the latter as the benchmark.
- *Task-based*: This approach is suggested for each task separately because it is difficult to compare evaluation results of multiple tasks and applications with each other. This approach can assess the usability and applicability of the ontology in its application domain.

2.2. OE aspects

In this section, several aspects of OE are discussed. Verdendic [15] identify and express in detail the six aspects [18] of ontologies: Syntax, Structure, Vocabulary, Semantics, Representation, and Context.

- *Syntax*: Ontologies can be expressed in a variety of several surface syntaxes such as N-Triples, RDF-XML, OWL Abstract Syntax, and the Manchester Syntax. This aspect represents various serializations in the different syntaxes.
- *Structure*: Structural measures are most commonly explored measures which are used in ontologies. These measures are breadth, depth, density, tangledness, fan-outness, particular difference, modularity, degree of distribution, and logical adequacy. This aspect evaluates the formal structure of ontology.
- *Semantics*: This aspect represents the semantic characteristic of the ontology. Generally, semantic characteristics are more interesting than the structure of ontology, especially during merging ontologies. Semantic aspects measure the stability of any ontology by converting the weak ontologies to stable ontologies.
- *Vocabulary*: The vocabulary of any ontology is considered as the set of all names in that ontology; it might be a literal or URI references, i.e. a value with a language identifier or datatype. In ontologies, the type of a name may often be inferred, e.g. a triple like ns:XXX rdf:type ns:Man will let us infer that ns:XXX is an owl:Individual and ns:Man an owl:Class.
- *Representation*: Representational aspects are handled with the relation between the structure and the semantics, i.e. the way to represent the semantics structurally. In order to evaluate representation features, it is required to compare the results of the semantic measures to the results of the structural measures.
- *Context*: This aspect deals with the ontology features when compared with other artifacts in ontology environment, which might be, e.g. a data source that the ontology expressed, an application using the ontology, or prescribed requirements across the ontology such as competency questions. For example, these competency questions should be described in a query language which can be applied in any application.

2.3. OE criteria

Several criteria [19] are discussed in this section for OE. Gomez-Perez suggests the two terms: ontology verification and ontology validation. The verification ensures that ontology has been designed correctly and it also examines the encoding of the specification. Validation ensures that the correct ontology has been designed and it refers to whether the meaning of the definitions meets with the conceptualization.

- *Correctness or accuracy*: This criterion ensures that ontology correctly captures and represents the aspects of the real world. A higher accuracy can be achieved by meaningful definition and description of classes, properties, and instances.
- *Adaptability*: This criterion measures how far the ontology entertains its applications. It should offer a conceptual foundation for a wide range of entertaining

tasks and ensures that the ontology can be extended without removing axioms.

- *Clarity*: Clarity measures that how ontology communicates the expected meaning of the defined terms. The definition of terms should be absolute and straight. Names of terms should be unambiguous and understandable. The ontology should prefer a definition rather than a class description.
- *Completeness or competency*: This criterion measures the appropriate coverage of the domain. The ontology should be able to answer all types of queries. Completeness has several aspects: all concepts, individuals, and relations are properly captured and represented lexically. Completeness is also called recall.
- *Computational Efficiency*: This criterion measures the capability of the used tools to interact with the ontology. It focuses especially on reasoners for the required tasks such as consistency checking, classification, and question answering.
- *Conciseness*: This criterion examines if the ontology contains irrelevant elements or redundant semantic representations. The ontology should focus on a minimal ontological commitment. Only required elements should be described.
- *Consistency or coherence*: Consistency ensures that the ontology does not contain or permit for any contradictions. It ensures about the formal and informal descriptions as well as logical consistency and matches the documentation with the specification.
- *Organizational fitness*: This criterion decides how easily an ontology can be deployed within an organization. Ontologies are often expressed using an ontology engineering methodology or by using particular data sets. So the ontology metadata should describe the tools, data sources, methodology, and organization.

2.4. OE tools

Several OE tools [20] have been discussed in this section. The common thing among them is, either they are verification tool which ensures that ontology is designed correctly or they are validation tool which ensures that ontology [21–23] expresses the real world. These tools are categorized here.

- *OntoClean*: In this approach, four features (Identity, Rigidity, Dependence, and Unity) are considered to recognize suspicious areas that ask for reexamination. Based on these features, classes can move up and down in the hierarchy and new classes can be created or deleted in the hierarchy to remove the problems.
- *oQual*: This tool evaluates the ontology based on three dimensions: functional, structural, and usability profiling. Functional dimension analyzes the relationship of ontology and its meaning. Structural dimension analyzes the semantics and syntax of the ontology and usability profiling focus on the annotation context of the ontology.
- *AKTiveRank*: This tool analyzes the related ontologies and their terms that are entered by the user. It uses four measures (class match, semantic similarity, density, and betweeness) to evaluate the ontology schemas.
- *ODEval*: This tool is used for the automatic detection of expected syntactical issues in ontologies such as presence of cycles in the inheritance tree of the classes, incompleteness, inconsistency, and redundancy of classes and instances.
- *OntoMetric*: OntoMetric is a metric-based tool that consists of 160 aspects spread across 5 dimensions to evaluate the suitability and quality of ontologies. The dimensions are: ontology content, language, building tools, development methodology, and usage costs.
- *OntoQA*: In OntoQA, the quality of a populated ontology is defined as a set of five schema quality features and nine knowledgebase (or instance-base) quality features. OntoQA divided the metrics into two categories: schema metrics and instance metrics.
- *ONTOCOM*: It is a cost estimation tool [24] for ontology development processes such as ontology building, maintenance, and reuse. It has five ratings from very low to very high and calculates the space and time complexity by using cost estimation formula.

3. Evaluation of MRO

The evaluation approach of MRO is categorized into two phases: Verification (building the ontology correctly) and Validation (building the correct ontology). In verification phase, two layers (lexical and structural) are applied. Lexical layer is evaluated through human-based approach while the structural layer is evaluated through evaluated through metric-based, criteria-based and cost-based approaches. A tool 'QueryOnto' has been successfully designed for Searching, Reasoning and Visualization of MRO. This tool is also used in the validation phase of evaluation. In this section, the complete evaluation of MRO has been done by using various tools; some of them are available online like OntoMetric and OOPs while others are available offline like protégé and 'QueryOnto'.

3.1. Evaluation approach by verification

Verification checks the encoding of the specification. Verification confirms that the ontology has been built in accordance with the specified quality criteria.

(1) *Lexical layer*: The lexical or vocabulary layer includes criteria relevant to the syntactic elements of ontologies. The vocabulary of ontology is the set of all names in that ontology. Human-based evaluation is applied and CamelCase is used for naming.
(2) *Structural layer*: At structural layer, metric-based (quantitative) evaluation, and criteria-based (qualitative) and cost-based evaluation have been carried out for verifying MRO.

(i) *Metric-based evaluation*

The OntoMetric tool has been used for metric-based evaluation. In OntoMetric, MRO is evaluated based on five metrics: Class metric, Schema metric, Base metric, Instance metric, and Graph metric. All these metrics are used to evaluate the MRO. Metric measures are presented in Table 1 and compared results are shown in Section 3.3.

- *Class metric*: It examines the classes and relationships of ontology by measuring the Class Importance (CI), Class Readability (CR), and Class Instance Count (CIC) of a specific class. In Table 1, all these metrics are measured for a class *140_AAD_Regiment* of MRO.
- *Schema metric:* Schema metric focuses on the ontology design for addressing the Richness of Attributes, Inheritance, and Relationship as well as a Ratio of Axioms and Classes, Equivalence and Inverse Relations of an ontology schema design. These metrics are measured for MRO and discussed in Table 1.
- *Base metric*: OntoMetric and Protégé tools are used to measure the base metric. Both tools are applied and the results are found to be similar as presented in Table 1. Base metric includes simple metric such as: number of Classes, Axioms, Objects, Properties, Individuals, and many more.
- *Instance metrics:* Instance metric represents a metric that expresses the knowledge base as a whole, and defines the way by which each class is being utilized in the knowledge base. This metric is calculated by measuring Average Population (AP) and Class Richness (CR). AP indicates the number of individuals compared to the number of classes. Class Richness indicates that how instances are arranged across the classes.
- *Graph metrics:* This metric evaluates the ontology structure such as number of Root Nodes, number of Leaf Nodes, number of Sibling Nodes, Depth and Breadth. The total number of root nodes is presented by Absolute Root Cardinality, the number of leaf nodes is represented by Absolute Leaf Cardinality, and the number of sibling nodes is represented by Absolute Sibling Cardinality. Depth property is related to the cardinality of paths while cardinality of levels is measured by Breadth property as shown in Table 1.

(ii) *Criteria-based evaluation*

Several criteria are discussed in Section 2.3. of the OE. For criteria-based evaluation, OOPs web-based tool is used. OOPs is a significant and a freely available tool for evaluation of ontologies [23]. This tool identifies the most common pitfalls of ontologies. OOPs is a platform independent online tool which diagnoses errors in ontologies according to a pitfall catalog which is currently containing 41 types of errors. It supports ontology developers to obtain general pitfalls during ontology verification. Nonetheless, the tool is not sufficient to repair

Table 1. Evaluated metrics of MRO.

SN	Metric	Attributes	Values
1	Class Metric (140_AAD_ Regiment)	Class Importance (CI)	0.00655
	Class Readability (CR)	3	
	Class Instance Count (CIC)	3	
2	Schema Metric	Attribute Richness (AR)	0.051852
		Inheritance Richness (IR)	1.059259
		Relationship Richness (RR)	0.050885
		Equivalence Ratio (ER)	0.009877
		Axiom/class Ratio (AR)	4.91111
		Inverse Relation Ratio (IRR)	0.0625
		Class/relation Ratio (CR)	0.896018
3	Base Metric	Axioms Count (AC)	1989
		Class Count (CC)	405
		Object Property Count (OPC)	16
		Data Property Count (DPC)	21
		Individual Count (IC)	458
4	Instance Metric	Average Population (AP)	1.130864
		Class Richness (CR)	0.145679
5	Graph Metric	Absolute Root Cardinality (ARC)	12
		Absolute Leaf Cardinality (ALC)	300
		Sibling Cardinality (SC)	405
		Depth	2037
		Breadth	405

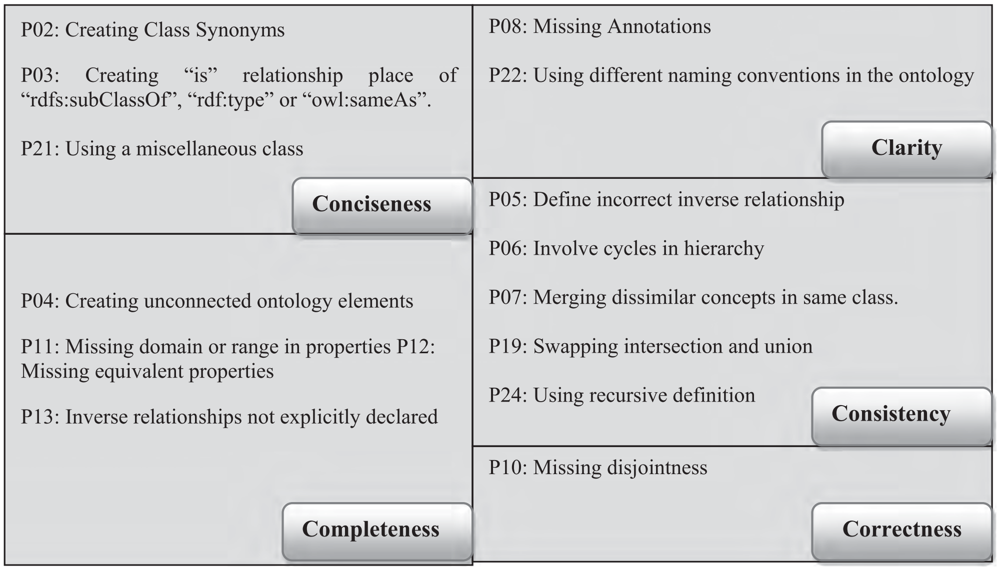


Figure 1. Pitfalls based on criteria.

Table 2. Pitfalls detected in MRO.

Pitfall No	Pitfall Description	Importance Level	Cases	Aspects	Affects to
P05	Defining the wrong inverse relationship	Critical	1	Wrong Inference	Object Properties
P04	Creating Unconnected Ontology elements	Minor	2	Completeness	Classes, Object and Data properties
P08	Missing Annotations	Minor	132	Ontology Clarity	Classes, Object and Data properties
P11	Missing domain or range of properties	Important	2	No Inference	Object and Data properties
P13	Inverse relationship not explicitly declared	Minor	14	No Inference	Object properties
P19	Defining multiple domain and ranges in properties	Critical	9	Wrong Inference	Object and Data properties
P21	Using a miscellaneous class	Minor	3	Modeling Decisions	Classes
P22	Using different naming conventions in the ontology	Minor	–	Ontology Clarity	Ontology
P30	Equivalent class not explicitly declared	Important	2	No Inference	Classes
P41	No license declared	Important	–	Ontology Metadata	Ontology

the existing inconsistencies; this must be done by the ontology developer.

OOPs Pitfall scanner detects most errors in the ontology and suggests for improvements. These pitfalls are categorized based on three types: minor, critical, and important.

- *Critical*: It is important to remove this pitfall. It might affect the ontology reasoning, consistency, and applicability.
- *Important*: Though not critical for ontology function, but it is important to remove this type of pitfall.
- *Minor*: It is not really a problem, but by correcting it, this ontology would become more authenticated.

These types are further grouped on the basis of some criteria such as correctness, conciseness, clarity, completeness, and consistency as discussed in Figure 1. In Figure 1, we have grouped some pitfalls, based on several criteria.

Table 2 depicts that there are five minor three important and two critical pitfalls in MRO. Minor and important pitfalls are not major issues, but critical pitfall should be removed from the ontology.

In MRO evaluation, there are two critical pitfalls (P05 and P19) which have been permanently removed from the ontology. These pitfalls are removed by enhancing the ontology such as P05 (Defining the wrong inverse relationship) due to incorrect domain and range of concept and p19 (Defining multiple domain and ranges in properties) which is related to the common error that results when defining multiple domains and ranges. In MRO, *has_repaired* and *repaired_by* properties are formed in an inverse relationship but have the same domain and range. We have changed the domain and range of both properties and remove this pitfall from the ontology. P11 (Missing domain or range of properties) pitfall identified as important due to some properties are missing to declare their domain and range and P30 (Equivalent class not explicitly declared) pitfall also identified as important due to some equivalent classes are not explicitly declared which need to be removed from the ontology. There are two cases of P11 and P30. All critical and important pitfalls are removed from the ontology. After removing critical and important pitfalls from the ontology, there

Table 3. Cost Drivers Rating Scale.

		Rating Scale				
S.No	Cost Drivers	Low	Very Low	Nominal	High	Very High
1.	DCPLX (Domain Complexity)	0.70	0.85	1	1.30	1.60
2.	ICPLX (Implementation Complexity)	0.85	0.85	1	1.30	1.30
3.	OE (Ontology Evaluation)	0.80	0.85	1	1.15	1.30
4.	DATA (Instantiation Complexity)	0.80	0.90	1	1.30	1.60

are five minor (P04, P08, P13, P21, and P22) pitfalls as in Table 2. These minor pitfalls have been removed by applying needful solution such as adding annotations, by declaring an inverse relationship and by following the naming conventions.

(iii) *Cost estimation-based evaluation*

ONTOCOM is a significant tool that is used to detect the economic features of knowledge for the development of ontology. It handles by measuring the development effort required to design ontology. ONTOCOM [24] uses a parametric formula to evaluate the efforts. There are three phases for Ontology Development: Ontology Building, Ontology Maintenance and Ontology Reuse. The total size can be calculated as: Size_B + Size_M + Size_R. In this paper, size of building is calculated as Size_B = (concepts + relation + instances)/1000.

ONTOCOM has identified 20 effort multipliers (Cost Drivers) that have a rating level for statistical analysis. Table 3 will represent the rating level of Cost Drivers. To predict the space complexity five ratings from very low to very high are assigned with each cost driver. High or Very High rating of size means that the ontology modeled was complex and it had a High or Very High impact on the design effort. On the other hand, if the ontology modeled is simple in nature the rating should be Low or Very Low.

Space complexity [24] of MRO is estimated by the size of the ontology to be designed and represented in various ontology primitives such as concepts, relations instances, and axioms in MRO 405 classes, 37 relations, and 1989 axioms. The size parameter of the estimation

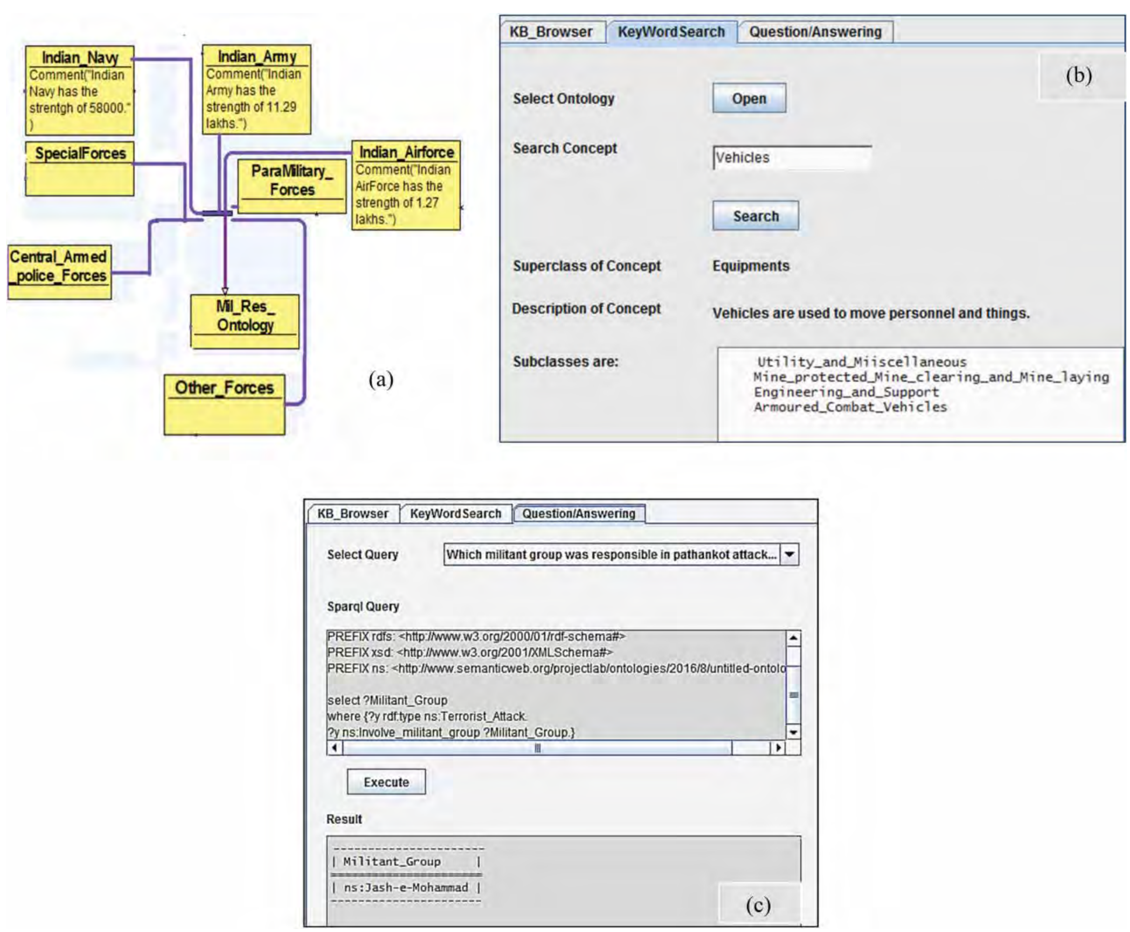


Figure 2. (a) Visualization, (b) keyword Search, and (c) question/answering.

[24] formula will be calculated as follows:

$$\text{Size of MRO} = \frac{(405 + 37 + 1989)}{1000}$$
$$= 2.421 \text{ kilo entities.}$$

According to the size, rating scale of OE is greater than the given scale of 'very high' which shows that the modeled ontology was heavy weighted due to large number of relations, axioms, and concept.

3.2. Evaluation approach by validation

In this approach, it needs to focus that 'Are we building the correct ontology?'. Ontology validation is usually the only way to ensure the correctness of the knowledge encoded in the ontology. The validation MRO is carried out in two layers: semantic layer and application layer.

(1) *Semantic layer*: Various formal and informal competency questions have been introduced to measure the competency of MRO. Competency questions are the questions that the ontology should be able to answer.

Table 4. Competency questions with SPARQL.

Sr. No.	Competency Questions
1.	CQ1: *Which Militant group was responsible for Pathankot Attack?* PREFIX ns: < http://www.semanticweb.org/projectlab/ontologies/2016/8/untitled-ontology-23# > Select ?Militant_Group where {?y rdf:type ns:Terrorist_Attack. ?y ns:Involve_militant_group ?Militant_Group} Sparql Results: Jash-e-Mohammad
2.	CQ2: *Display the name of the workshop which was used in Operation_Parakram.* Sparql PREFIX ns: < http://www.semanticweb.org/projectlab/ontologies/2016/8/untitled-ontology-23# > Select ?workshop WHERE { ?workshop rdf:type ns:Workshops. ?workshop ns:Used_In ns:Operation_Parakram. } Result: 515_Army_Base_Workshop
3.	CQ3: *Which workshop can provide maintenance support for location Delhi?* Sparql PREFIX ns: < http://www.semanticweb.org/projectlab/ontologies/2016/8/untitled-ontology-23# > Select ?workshop WHERE { ?workshop rdf:type ns:Workshops. ?workshop ns:Located_In ns:Delhi. } Result: 505_Army_Base_Workshop
4.	CQ4: *Display the strength of Igla missile.* Sparql PREFIX ns: < http://www.semanticweb.org/projectlab/ontologies/2016/8/untitled-ontology-23# > Select (COUNT(?x) AS ?strengthofIglaaMissile) where {?x rdf:type ns:9K38Igla.} Result: 5

A tool 'QueryOnto' has been designed to accomplish the above-mentioned task. This tool is developed by using Java and Jena API. The use case 'question Answering' of QueryOnto plays an important role in the semantic layer evaluation of MRO. *The framed com*petency questions are written in natural language and are based on various military resources such as: Workshops, Location, Equipments, Operation, and many more. A question can be selected from the combo box like 'Display the name of the workshop which was used in Operation Parakram?', as the question is selected, the SPARQL query is also displayed, then execute the query and the result will be displayed in the Result box as in Figure 2(c). In MRO, competency questions are grouped in a cluster such as *Decision Making Query, Teaching and Training, Tactical Operation* [10]. Some examples of CQs are discussed in Table 4. These CQs are successfully executed on 'QueryOnto' tool in an efficient manner. It returns accurate results which fulfill all five criteria such as Clarity, Completeness, Correctness, Conciseness, and Consistency.

(2) *Application layer*: In this layer, application-based evaluation has been done for validating the ontology. An application-based evaluation is performed by utilizing two use cases 'Keyword Search' and 'Visualization' of the tool QueryOnto. The details of any concept of MRO can be searched and responses can

Table 5. Comparison of metrics.

Metrics	Military Resource Ontology	Munnin-Ontology
Class count	405	159
Object property	16	15
Data property	21	5
Total property	31	20
Class richness	0.145679	0.106918
Attribute richness	0.51852	0.031447
Inheritance richness	1.059259	0
Absolute depth	2037	159
Absolute breadth	405	159

Table 6. Detected pitfalls.

S. No.	Detected Pitfalls on OOPs!			After Correction
1.	Minor P04, P08, P13	Important P11, P30	Critical P05, P19	No Pitfalls

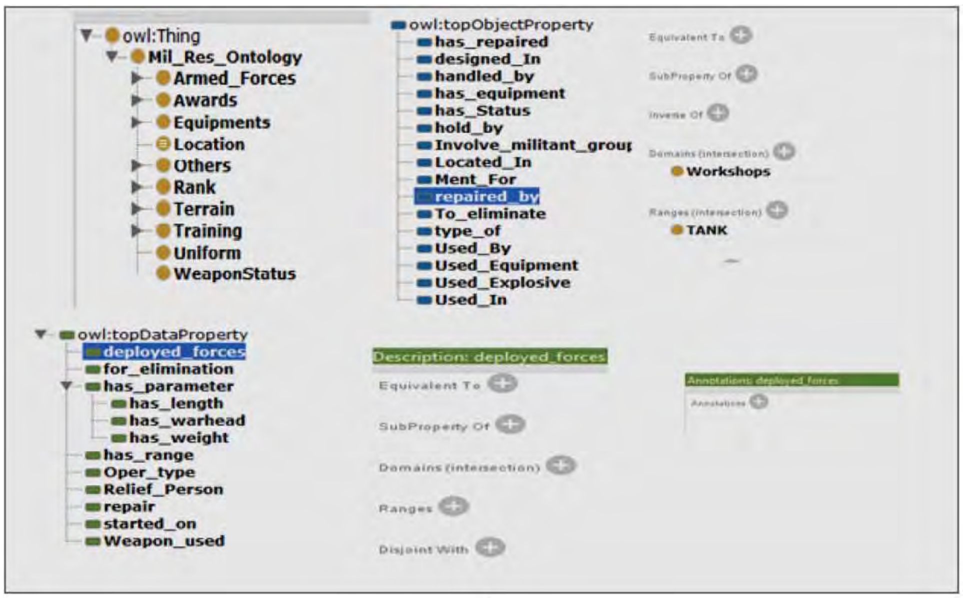
Table 7. Assessment of QueryOnto.

S. No.	Content	Quantity	Result
1.	Competency Questions	50 CQs	100% executed
2.	Concept Searched	200 Concepts	98% successfully searched
3.	Visualizing Concept with Comments and properties	All concepts	100% visualized

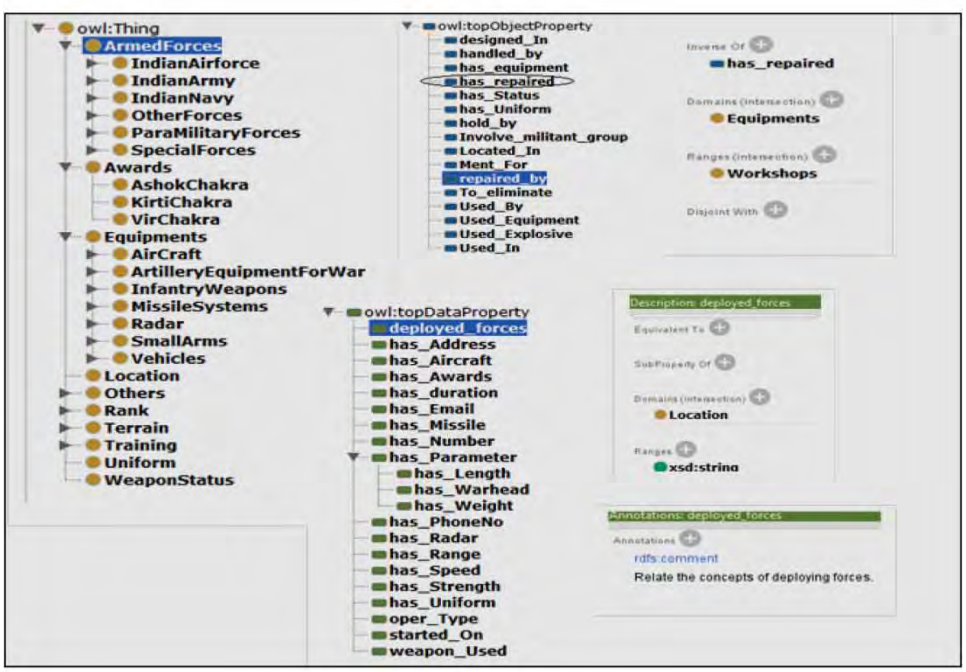
be generated in a time-bound manner. All modules are briefly discussed in Figure 2.

(3) *Visualization*: In this module, the ontology is displayed in the graph view. In this paper, graph visualization has been done by using OWLGred tool. This tool has been plugged in this module for the graph visualization. It shows classes, subclasses, properties, and axioms. Figure 2(a) shows the graph view of MRO. It shows the top classes of Indian Defence.

(4) *Keyword search*: In this module, we can search any concept of MRO. This module focuses on an efficient search for any specific concept of ontology. In Figure 2(b), MRO is selected and enters a text 'Vehicles' for search. It shows roots of concept, description of concept, properties, and sub-roots of the concept. It shows only relevant details of concept that has been searched from ontology. It performs a semantic search rather than syntactic only. It searches the concept in the knowledge base with its meaning. In the



(a)



(b)

Figure 3. (a) Ontology before evaluation and (b) ontology after evaluation.

semantic search, it returns correct and concise result and it is more consistent than syntactic search.

4. Results and discussion

After evaluating the MRO, results are shown with their description in this section.

- Results by Metrics

The metrics of MRO are evaluated on the OntoMetric tool in Table 1 and compared with the military ontology of Munnin-project [25]. Metric values are shown in Table 5.

- Result by Pitfalls

In Table 2, there were five minor three important and two critical pitfalls detected in MRO. Here minor and important pitfalls are not major issues, but critical pitfall should be removed from the ontology. After evaluation, in Table 6, we have analyzed that all minor, important and critical pitfalls have been removed from MRO.

- Result by Validation

Several concepts are searched on 'QueryOnto' tool and it returns an accurate and concise result within time. Several competency questions are executed for obtaining the correct result. In this tool, 50 questions are executed and obtained accurate results for all without any error. Similarly, 200 concepts of MRO are searched and obtained the complete description of all these concepts in optimized time as in Table 7.

In Figure 3(a), we have shown ontology before evaluation and in Figure 3(b), we have shown ontology after evaluation.

5. Conclusion

Today, Ontologies are looked into as a very crucial representation technique to overcome the problem of heterogeneity and diversity in IoT-generated data. This paper has focused on evaluation of MRO. Several approaches, aspects, criteria, and tools are discussed for OE. To evaluate the MRO, we have followed verification and validation approach by applying quantitative (Metric based, Criteria based) and qualitative (Application based, Competency questions) methods. OntoMetric tool has been used for metric-based evaluation and OOPs tool used for criteria-based evaluation. For application-based evaluation, a 'QueryOnto' tool is designed for executing competency questions, searching concepts and visualizing the ontology. Several metrics are evaluated and represented in the results. ONTOCOM is used to estimate the size of MRO.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by Defence Research and Development Organisation (DRDO, New Delhi) followed by the grant no ERIP/ER/1506048/M/01/1611.

Notes on contributors

Sanju Mishra Tiwari is working as a Research Associate in the research project of DRDO at the National Institute of Technology, Kurukshetra. She has published several research papers till date. She is in progress to work in the area of the Semantic Web Security Issues, Query Optimiztion and Otology Development.

Sarika Jain is Assistant Professor in Department of Computer Applications, National Institute of Technology, Kurukshetra. Her current research interests include Knowledge Based Systems, Intelligent Decision Support, Semantic/Intelligent Query Search Engines.

ORCID

Sanju Mishra http://orcid.org/0000-0001-7197-0766
Sarika Jain http://orcid.org/0000-0002-7432-8506

References

[1] Naranjo PGV, Pooranian Z, Shojafar M, et al. FOCAN: A fog-supported smart city network architecture for management of applications in the internet of everything environments. arXiv, 2017.
[2] Naranjo PGV, Pooranian Z, Shamshirband S, et al. Fog over virtualized IoT: new opportunity for context-aware networked applications and a case study. Appl Sci. 2017;7:1325.
[3] Gani A, Siddiqa A, Shamshirband S, et al. A survey on indexing techniques for big data: taxonomy and performance evaluation. Knowl Inf Syst. 2016;46(2):241–284.
[4] Jain S, Meyer V. Evaluation and refinement of emergency situation ontology. Int J Inform Educ Technol. 2018;8(10):713–719.
[5] LeBlanc EC, Nguyen DN, Balduccini M, et al. Military ontologies for information dissemination at the tactical edge. CEUR Workshop Proc. 2015: 1517.
[6] Dragos V. Developing a core ontology to improve military intelligence analysis. Int J Knowledge-Based Intell Eng Syst. 2013;17(1):29–36.
[7] Yoo D, No S, Ra M. A practical military ontology construction for the intelligent army tactical command information system. Int J Comput Commun Control. 2014;9(1):93–100.

[8] Smart PR, Russell A, Shadbolt NR, et al. Supporting civil-military information integration in Military Operations Other Than War. Int Conf Integr Knowl Intensive Multi-Agent Syst KIMAS. 2007; 434–439.
[9] Defence R, Valcartier DC, North P, Matheus CJ, et al. 10th International Command & Control Research and Technology Symposium. The Future of C2 : Coalition Interoperability Towards a Formal Ontology for Military Coalitions Operations Eric Dorion System Engineering & Architecture Group System of Systems Section. 2005.
[10] Shamshirband S, Anuar NB, Kiah MLM, et al. An appraisal and design of a multi-agent system based cooperative wireless intrusion detection computational intelligence technique. Eng Appl Artif Intell. 2013;26(9): 2105–2127.
[11] Mishra S, Jain S. Towards a Semantic Knowledge Treasure for Military Intelligence. Proceedings of the 1st International Conference on Emerging Technologies in Data Mining and Information Security (IEMIS), Feb 23–25, Kolkata. Advances in Intelligent Systems and Computing (AISC). Cham: Springer; 2018.
[12] Fahad M, Qadir MA. A framework for ontology evaluation. CEUR Workshop Proc. 2008;354:148–156.
[13] Hooi YK, Hassan MF, Shariff AM. Ontology evaluation – a criteria selection framework. Int Symp Math Sci Comput Res. 2015: 298–303.
[14] Bandeira J, Bittencourt II, Espinheira P, et al. FOCA: A Methodology for Ontology Evaluation. arXiv preprint arXiv:1612.03353. 2016; 3: 1–23.
[15] Hlomani H. Multidimensional data-driven ontology evaluation. 2014. p. 155.
[16] Thuan N H, Antunes P, Johnstone D. A decision tool for business process crowdsourcing: ontology, design, and evaluation. Group Decis Negot. 2018;27(2):285–312.
[17] Delir Haghighi P, Burstein F, Zaslavsky A, et al. Development and evaluation of ontology for intelligent decision support in medical emergency management for mass gatherings. Decis Support Syst. 2013;54(2):1192–1204.
[18] Pak J, Zhou L. A framework for ontology evaluation. Explor. Grand Chall Next Gener E-bus. 2011;52:10–18.
[19] Vrande D. Ontology evaluation. Handb. Ontol. 2010; 16(6):251–274.
[20] Bilgin G, Dikmen I, Birgonul M T. Ontology evaluation: An example of delay analysis. Procedia Eng. 2014;85:61–68.
[21] Mishra S, Jain S. A unified approach for OWL ontologies. IJCSIS. 2016;14(11):747–754.
[22] Mishra S, Jain S. A study of various approaches and tools on ontology. Proceedings – 2015 IEEE international conference on computational intelligence and communication technology. CICT; 2015.
[23] Mishra S, Malik S, Jain NK, et al. A realist framework for ontologies and the semantic Web. Procedia Comput Sci. 2015;70:483–490.
[24] Abdul P, Ragab M. 'OCET' ontology cost estimation tool. Int J Comp Sci Inform Technol Secur. 2012;2(2):237–244.
[25] http://rdf.muninn-project.org/ontologies/documents.html
[26] Usip PU, Umoren EM, Inyang UG, et al. An ontology-based temporal scheduling and complexity reduction model for timetabling knowledge management. Adv Sci Technol Eng Syst J. 2017;2(3):1585–1591.