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Semantic assessment of smart healthcare ontology

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Abstract

Purpose – Health-care ontologies and their terminologies play a vital role in knowledge representation and data integration for health information. In health-care systems, Internet of Technology (IoT) technologies provide data exchange among various entities and ontologies offer a formal description to present the knowledge of health-care domains. These ontologies are advised to assure the quality of their adoption and applicability in the real world.

Design/methodology/approach – Ontology assessment is an integral part of ontology construction and maintenance. It is always performed to identify inconsistencies and modeling errors by the experts during the ontology development. A smart health-care ontology (SHCO) has been designed to deal with health-care information and IoT devices. In this paper, an integrated approach has been proposed to assess the SHCO on different assessment tools such as Themis, Test-Driven Development (TDD)onto, Protégé and OOPs! Several test cases are framed to assess the ontology on these tools, in this research, Themis and TDDonto tools provide the verification for the test cases while Protégé and OOPs! provides validation of modeled knowledge in the ontology.

Findings – As of the best knowledge, no other study has been presented earlier to conduct the integrated assessment on different tools. All test cases are successfully analyzed on these tools and results are drawn and compared with other ontologies.

Originality/value – The developed ontology is analyzed on different verification and validation tools to assure the quality of ontologies.

Keywords Health care, IoT, Ontology assessment, Knowledge modeling, Linked data, Test cases

Paper type Research paper

1. Introduction

Integration of massive data sets provides the growing knowledge discovery and ontologies organize the domain knowledge as significant concepts, relations, axioms and instances. In health-care domains, ontologies organize the healthcare information for encoding health resources, health records, lab tests and diagnosis of patients. A hierarchical relationship of concepts in ontology plays an important role in data integration, knowledge representation and decision support systems. IoT technologies offer to exchange the data between entities through the sensing devices for smart-health-care systems. The data can be health history, health sensing data, user's information, device and other domain-specific data. A specific data structure is required to generate the desired information in the smart-health-care

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system to interact with the connected devices. Semantic models are based on ontologies that are significant for the modeling of concepts and the relationship between the concepts. These models include health-care terminologies and relationships of terms for the representation of health information and connected devices. Semantic Web technologies are recognized as promising tools for interacting with several smart devices having strong skills to exchange their services and share data precisely. Healthcare information systems are suitable application areas where smart technologies are generally applied to provide an appropriate solution. An online health-care system needs to manage strongly structured and semantically generous health data in a heterogeneous environment. It is a challenging task to assure and assess the data quality of semantic technologies and deploying them on the Web as it is termed that "data quality is not an absolute measure, but assesses fitness for use" (Kontokostas *et al.*, 2014). Health-care domains have been at the front of the use and acceptance of Semantic Web technologies for efficient health-care treatment and diagnosis. General and formal ontologies such as ICD-10 (1992), Snomed-CT (Wade and Rosenbloom, 2008) and International Classification of Functioning (ICF) (Kumar and Smith, 2005) provides a vocabulary along with their definition and relationship. These ontologies are considered as upper ontologies and can integrate with any new modeled ontology to make it more expressive.

Smart healthcare ontology (SHCO) is designed (Tiwari *et al.*, 2018; Mishra and Jain, 2019a, 2019b, 2018) for monitoring doctors and patients anytime, anywhere, and can modify prescriptions when required. This ontology is a formal description of the structure and it is described in Resource Description Framework (RDF) [W3C], Resource Description Framework schema (RDFs) [W3C] and Web Ontology Language (OWL) [W3C]. SHCO is presented as a semantic model by extracting health-care knowledge such as doctor-patient records, recommended diagnosis and treatment policies. Ontologies can have different data quality problems such as interoperability, inconsistency or representational issues. To improve the interoperability between smart health care and end-users it is must to assess the quality of modeled knowledge in ontology. There have been few approaches for assessing the ontologies and semantic web quality. Quality assurance (Amith *et al.*, 2018) of ontologies analyzes the extrinsic and intrinsic aspects of the proposed ontology and examines the inconsistencies and modeling errors. Extrinsic aspects are for the coverage of user and domain-specific requirements while intrinsic aspect focuses on the content of ontology (concept, concept hierarchy and individuals) to assess completeness, correctness, consistency, clarity and conciseness. It is essential to assess the quality of ontology to examine logical or syntactic problems that are often considered as unintended consequences of the ontology. It is must to define all concepts with their definition and must not lead to inconsistency. Several methodologies (Corcho *et al.*, 2003) frameworks are available to assess the data quality, all addressing different aspects such as measures, tools and methodology. Generally, ontologies have three main components (TBox, ABox and RBox) are formalized to form the semantic model, TBox organizes the terminology of concepts/classes and their relations, ABox organizes the materialization of concepts and relations and RBox organizes the rules such as SWRL and SQWRL. In SHCO, TBox represents the concepts and relations and ABox represents the concept instances and relation instances to realize the real-world objects.

In this paper, a methodology is proposed to assess the proposed semantic model of SHCO based on the different test cases modeled in the ontology. The SHCO has been assessed on different verification [TDDonto (Lawrynowicz and Keet, 2016), Themis (Fernandez-Izquierdo and Garcıa-Castro, 2018)] and validation [OOPs! (Poveda-Villalón *et al.*, 2014), Protégé (Noy and McGuinness, 2001; Gennari *et al.*, 2003)] tools based on several dimensions (completeness, consistency, conciseness, correctness and clarity). It is must to evaluate the proposed ontology before its publishing on linked data; this paper addresses three main contributions to assess the SHCO so inconsistencies and modeling errors can be removed from the ontology.

(1) Proposed methodology and approaches to assess the ontology quality.

(2) Modeled test cases for the assessment of SHCO.

(3) Evaluating all test cases on several tools (Themis, TDDonto, Protégé and OOPs!).

These contributions are mainly focused on intrinsic dimensions of the ontology such as semantic accuracy, syntactic validity and consistency and aims to identify inconsistencies or modeling errors to resolve them and enhance ontology quality. In the first contribution, a methodology is proposed to follow the steps to accomplish the quality assessment of ontology. In the second contribution, test cases are modeled to evaluate the SHCO based on different requirements. Finally, all test cases are examined on several tools and presented the results, based on the modeled test cases.

The remaining of the paper is organized as follows: Section 2 presented the existing work and motivation for assessing the quality of ontology; Section 3 presented the proposed methodology for quality assessment of ontology; Section 4 presented the ontology assessment by evaluating the test cases on different tools; Section 5 presents the result; Section 6 concludes the paper.

2. Related works

Several research studies attempt to focus on exploring the quality assessment of ontologies. This section presents an overview of the existing works in the context of ontology quality assessment approaches. This section will discuss about the relevant existing ontology assessment tools and also presented an evaluation summary of the existing smart health-care ontologies. Table 1 analyzed 14 ontology assessment tools to check the quality of ontology with different dimensions. These tools are categorized in three types such as plugins, editors and Web-based applications. Table 2 analyzed 8 smart health-care ontologies from 2015 to 2020 with their different dimensions.

It is analyzed in Table 1 that some tools are used as plugins while others are used as Web-based applications and editors. There are five tools (*TDDonto, OntoCheck, XD-Tools, OntoClean and ODEval*) are used as plugins, seven tools (*OOPs!, ONTOQA, Themis, Ontometric, Ontokeeper, Moki, OQuaRE*) are used as a Web-based application and two tools (*Protégé, S-OntoEval*) are used as standalone editor.

It also observed that OntoClean and ODEval tool only checks the RDFs and do not assess the OWL schema (Instances). In this study, the proposed ontology SHCO is assessed on four ontology assessment tools (*Protégé, TDDonto, Themis and OOPs!*) where *Protégé* is an editor with reasoners, *TDDonto* is a plugin of Protégé, *Themis* and *OOPs* are Web-based applications to check the ontology quality. Table 2 has discussed the existing health-care ontologies with their different dimensions to analyze whether the proposed ontologies are checked for their qualities.

A bipolar disorder (BD) (Thermolia *et al.*, 2015) ontology has been designed to model the relevant concepts, relations and attributes that are needed for disorder, as well as treatment diagnosis and monitoring. BD ontology is designed by using Protégé editor and performed an initial assessment by SWRL rules to answer the questions.

Sherimon and Krishnan (2016) have presented an ontology-based decision support system "OntoDiabetic" to assess the risk factor and suggest treatment for diabetic patients.

Table 1. Characterization of ontology assessment tool

Sno.	OE tools	Reference	Measure	Availability	Quality aspects	Evaluation	Considered
1	**OOPs!**	Poveda-Villalón *et al.* (2014)	By detecting ontology inconsistencies	Web-based tool	Completeness, correctness, conciseness, clarity, consistency	Ontology schema and population	**Yes**
2	ONTOQA	Tartir and Arpinar (2007)	By ranking according to the metrics (schema and instance)	Web-based tool	Class and instance importance, readability, connectivity	Ontology schema and population	No
3	**TDDonto**	Lawrynowicz and Keet (2016)	By assessing the TBox and ABox	Protégé plugin	Covers class subsumption	Ontology schema and population	**Yes**
4	**Protégé**	Noy and McGuinness (2001)	By providing high-performance reasoning	Ontology editor with reasoner	Classification (subsumption), consistency checking, instance classification	Ontology schema and population but not supporting multiple inheritance	**Yes**
5	**Themis**	Fernández-Izquierdo and Garcıa-Castro (2019)	Validating ontologies based on functional ontology requirements	Web-based tool	Formalization of requirements into tests cases	Ontology schema and population	**Yes**
6	Ontometric	Lozano-Tello and Gómez-Pérez (2004)	Validating ontologies based on different metrics	Web-based tool	Content, language, methodology, tool and costs	Ontology schema and population	No
7	OntoKeeper	Amith *et al.* (2018)	By semiotic measures	Web-based tool	Interpretability, consistency, clarity	Ontology schema and population	No
8	S-OntoEval	Dividino *et al.* (2008)	By assessing logical inconsistencies	Stand-alone application	Assessing the syntactic, semantic and pragmatic aspects of ontology quality	Ontology schema and population	No
9	OntoCheck	Schober *et al.* (2012)	Metadata aspects	Protégé plugin	Labeling error detection and curation	Ontology schema and population	No
10	XD-Tools	http://neon-toolkit.org/wiki/XDTools	By checking structural and architectural ontology features	NeOn plugin	Structural architecture	Ontology schema and population	No

(continued)

Table 1.

Sno.	OE tools	Reference	Measure	Availability	Quality aspects	Evaluation	Considered
11	Moki	Pammer (2010)	Assessing implications of formal axioms	Web-based tool	Ontology evaluation functionalities	Ontology schema and population	No
12	OQuaRE	Duque-Ramos *et al.* (2011)	Extracts quality measurements from the ontology structure	Web-based tool	Quality model and quality matrices	Ontology schema and population	No
13	OntoClean	Guarino and Welty (2004)	Inappropriate and inconsistent modeling choices	WebODE plugin	Rigidity, identity, unity and dependence	Ontology schema	No
14	ODEval	Corcho *et al.* (2004)	Checks for the correctness of the taxonomy	WebODE plugin	Inconsistency, incompleteness and redundancy	Ontology schema	No

They have modeled this ontology and offered reasoning by using OWL2 rules and reasoned but they did not validate the modeled knowledge.

A HealthIoT ontology has designed by Rhayem *et al.* (2017) to model the semantics of associated devices and knowledge in internet of medical things. This ontology provides a semantic interoperability with health-care devices and information. HealthIoT ontology is assessed with inbuilt reasoners during its modeling and SWRL rules are framed to inferred with the proposed ontology.

SAREF4Health ontology is an extension of SAREF (Moreira *et al.*, 2018), a framework for smart appliances references. This ontology is evaluated by implementing the ontology in RDF with Protégé tool. It is validated by the competency question for assessing the completeness of SAREF4Health ontology. SPARQL is used to answering the competency question.

A semantic model is presented by Jin and Kim (2018) to promote semantic interoperability by e-Health objects, server and clients. They have reused Semantic Sensor Network (SSN) to present meaningful information. SSN manages the sensing devices interoperability problems. An otology is designed for e-Health information by reusing SSN ontology and evaluated only by reasoner during its modeling.

A semantic data model has been designed to present the health and fitness data as an IoT fitness ontology (IFO) (Reda *et al.*, 2018) which formally describe the relevant concepts of IoT fitness and wellness appliances. This ontology is formalized in hierarchical structure and relates to the standard domain ontologies such as SNOMED-CT (Wade and Rosenbloom, 2008).

Linked Health Resource (LHR) (Peng and Goswami, 2019) ontology is modeled using RDFs and OWL standard to present the health-care information. LHR ontology has reused SSN-SOSA to link with IoT devices. This ontology is evaluated with reasoned and used SPARQL to check the completeness of modeled knowledge.

A health-care IoT-based system has been proposed by Sondes *et al.* (2019) to offer semantic interoperability among health-care devices and users. They have created a semantic model to integrate the health-related data, IoT devices and time. This model has been validated by querying answering with SPARQL and reasoning rules.

2.1 Motivation

Several health-care ontologies are semantically modeled to integrate the health-care information and linked with IoT devices but it is noticed that most of them are evaluated with inbuilt reasoners or with SWRL and SPARQL. As inbuilt reasoners checks only satisfiability, consistency and classification of its concepts at schema level but it does not

S No.	Healthcare ontology	Assessment approach	Online available	Reused ontologies	Year
1	BD	Initial evaluation by SWRL rules	No	NA	2015
2	OntoDiabetic	By inbuilt reasoner only	No	NA	2016
3	HealthIoT	SWRL rules for reasoning	No	NA	2017
4	SAREF4Health	Validation by Competency Questions and SPARQL	Yes	SSN, SAREF	2018
5	e-Health	By inbuilt reasoner only	No	SSN	2018
6	IFO	By a field expert, RML	No	NA	2018
7	LHR	By inbuilt reasoner and SPARQL	No	SSN, SOSA	2019
8	HealthcareIoT	By inbuilt reasoner only	No	NA	2019

Table 2.
Existing health-care ontologies

check the completeness of modeled knowledge. It is observed in the literature that existing health-care semantic models lacks for a complete verification and validation activity to assess the ontology quality. Therefore, we have proposed an integrated approach to assess the ontology on heterogeneous assessment tools for analyzing the ontology quality. As of our best knowledge, no any work has been found related with our approach to assess the quality of ontologies. Our work presented the assessment of ontology quality with different tools that are existing as plugins, editor and Web-based application and estimated a significant result.

3. Proposed methodology

There are several methodology approaches such as On-To-Knowledge (Staab *et al.*, 2001), DILIGENT (Pinto *et al.*, 2004) and METHONTOLOGY (Fernández-López *et al.*, 1999) are available for building the ontology. These methodologies provide the guidelines for developing ontologies but they all having some limitations (Gómez-Pérez and Suárez-Figueroa, 2009) for reusing and re-engineering of existing ontologies. These limitations have accomplished in NeOn (Gómez-Pérez and Suárez-Figueroa, 2009) methodology. This methodology provides a set of systematic guidelines for various activities and processes. These guidelines are described as procedurally, functionally and empirically with a descriptive examples sets. NeOn methodology supports several aspects of the ontology development process and reusing the ontologies in heterogeneous environment where knowledge is explored by multiple people such as ontology practitioners and domain experts (Amith *et al.*, 2018; Suárez-Figueroa *et al.*, 2012). After following these methodologies, a SHCO (Figure 3) has been designed and a methodology also proposed for the quality assessment of SHCO.

The information of SHCO is organized in the form of TBox (conceptual schema), ABox (instance schema) and RBox (rules). The proposed ontology consisting several elements such as health care, health devices, actor, disease, actuator and sensor to form the smart-health domain knowledge. TBox describes the general conceptual vocabulary of smart-health domains. It does not contain any individual or ABox elements. The smart-health-care domain knowledge describes the meta-model of healthcare, hence it is required to perform complete assessment. In this section, a methodology (Figure 2) is illustrated to assess the quality of SHCO by the verification and validation (Sabou and Fernandez, 2012) with several tools.

In this methodology, there are three layers: ontology layer for the TBox and ABox; reasoning layer for interacting with the ontology by the help of SWRL rules and SPARQL queries; user interface layer to access ontology layer and reasoning layer. In this methodology, four tools [Themis (Fernandez-Izquierdo and Garcıa-Castro, 2018), TDDonto (Lawrynowicz and Keet, 2016), Protégé (Noy and McGuinness, 2001; Gennari *et al.*, 2003) and OOPs! (Poveda-Villalón *et al.*, 2014)] in Figure 2 are used for assessing the quality of SHCO. Themis and TDDonto are used for the verification of requirements while Protégé and OOPs! are used to validate the modeled knowledge in the ontology as in Figure 1.

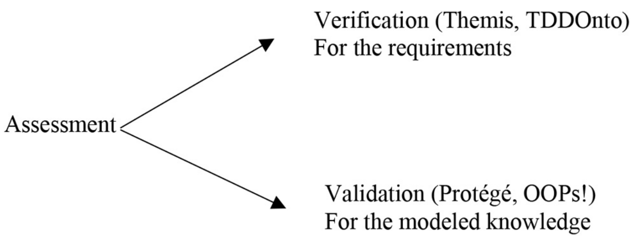


Figure 1.
Categorization of assessment tools

In Figure 3, there is a graphical representation of TBox and ABox of SHCO has been presented. We have 20 test cases to check on these tools for assessing the ontology. These test cases are generally designed for TBox (subClassOf, cardinality, equivalence, multiple inheritance, property between classes) and ABox (type of individual). SPARQL queries and SWRL rules are used for reasoning with the ontology. Reasoning proves the availability of both (TBox and ABox) data. A test expression guide is presented in Table 3 to show some major test cases. All test cases are framed based on these expression guides (Figures 2 and 3).

In SHCO, knowledge is modeled in different ways. All 20 cases are verified and validated on several tools to check the availability of modeled knowledge in the ontology. Several approaches have been followed to assess the ontology based on the proposed methodology. These approaches are discussed in Section 4.

4. Assessment of the smart health-care ontology quality

According to literature review, it is noticed that validation and evaluation approaches with different tools are the best way to assess the ontology quality. In this section, we have used four tools (Themis, TDDonto, Protégé and OOPs!) for assessing the ontology. We have designed 20 requirements to check on three tools (Themis, TDDonto and Protégé) and OOPs! Tool is used to check different quality measures such as *completeness, correctness, conciseness, consistency and clarity* for validating ontologies based on several pitfalls. We have explained all assessments in the following sub-sections.

Table 3. Test expression guide

Test criteria	Test expression syntax	Test expression in SHCO	Test case with requirement
T1 for individual in ontology	X type Y	Sam type KidneyPatient Jack type HeartPatient	Sam is a patient of kidney problem Jack is a patient of heart disease
T2 for SubClass	X subClassOf Y	Sensores subClassOf HealthDevices	A sensor is a health device
T3 for property between two classes	X subClassOf P some Y	HeartPatient subClassOf treated_by some Cardiologist	Heart patients should be treated by some cardiologist
T4 multiple inheritance	X subClassOf Y and Z	Oncologist subClassOf Physian and Doctor	Oncologist can be a Doctor or Physician
T5 MIN cardinality	X subClassOf P min [num] Y	BloodPressure subClassOf measured_by min 1 BPSensores	Blood pressure is measured by at least one device
T6 equivalence	X subClassOf Y	Doctor equivalentTo Physician	Doctor and Physician are equivalent entities
T7 MAX cardinality	X subClassOf P max [num] Y	Patient subClassOf has_address max 1 Address	Every patient has maximum one address
T8 disjointness	X disjointWith Y	Actuator disjointWith Sensores	An actuator cannot be a sensor
T9 SubClass	X subClassOf Y	BPSensores subClassOf Sensores	A BPSensores is a sensor
T10 disjointness	X disjointWith Y	HealthCare disjointWith HealthDevices	Health care cannot be health devices
T11 SubClass	X subClassOf Y	Diagnosis subClassOf Event	Diagnosis is an event

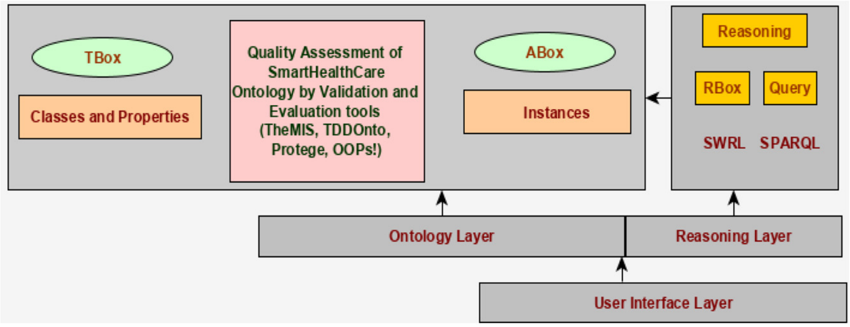


Figure 2. Proposed methodology for quality assessment of SHCO

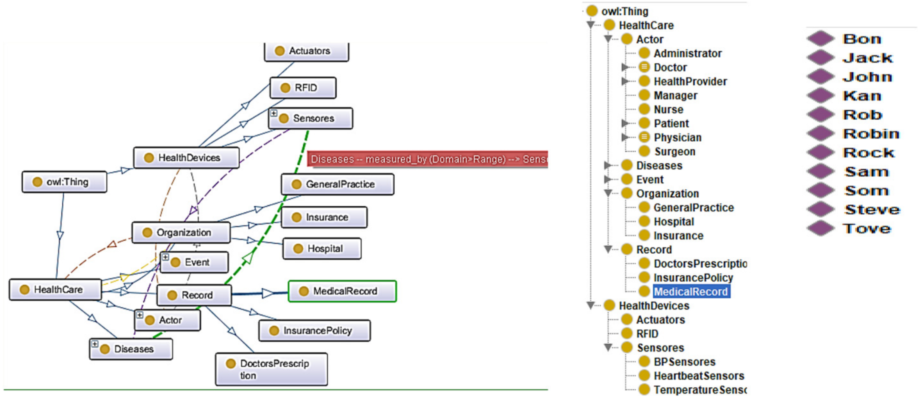


Figure 3. Graphical and hierarchical representation of TBoX and ABoX

4.1 Evaluation with Themis tool

Themis (Fernandez-Izquierdo and Garcıa-Castro, 2018) is an online tool for validating the ontology for testing its requirements. This is a testing tool for assessing the ontology behavior in multiple situations to analyze the modeled knowledge in the ontology. This tool uses OWL API (Horridge, and Bechhofer, 2011) to load the ontology and Pellet (Sirin *et al.*, 2007) reasoner to check the consistency of ontologies. There are 20 test cases framed to assess the SHCO on Themis tool. All these requirements successfully tested and passed. This tool produces four possible results for each test in the ontology:

(1) *Passed*: if the test case is successfully passed and the results of the test expressions are according to the modeled knowledge.

(2) *Undefined terms*: if the test case is not passed and results that test expressions are not modeled in the ontology.

(3) *Conflict*: if the test case is passed but the results are not according to the modeled knowledge which leads to a conflict in the ontology.

(4) *Absent relation*: in this, there is no conflict but results are not the desired one.

All test cases are examined in this tool and some of them are presented in Figure 4 with their possible results in the result section.

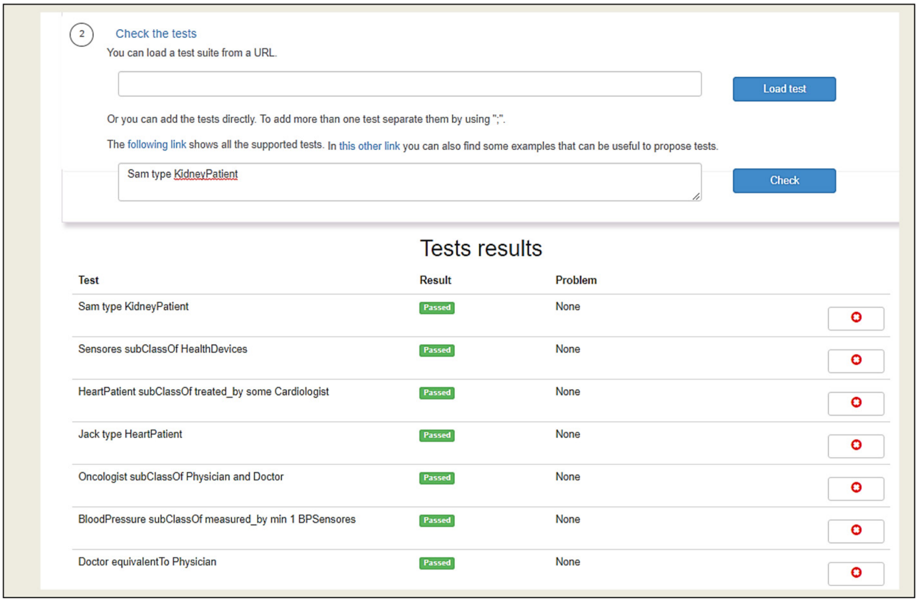


Figure 4.
Test results on Themis tool

4.2 Evaluation with TDDonto

TDDonto (Lawrynowicz and Keet, 2016) is a test driven development tool for assessing the TBox and ABox. TBox realize the TDD tests that focus on classes and properties while ABox tests present instance-level. These tests are based on SPARQL query with a reasoner and results in four possible forms: entailed, inconsistent, incoherent and absent.

(1) *Entailed*: if axiom is already modeled in ontology.
(2) *Inconsistent*: if axiom is not relevant and axiom cannot be added in the ontology.
(3) *Incoherent*: if axiom is not entailed and cause incoherent, hence cannot be added in the ontology.
(4) *Absent*: if axiom is not exist in the ontology and can be added without any inconsistency.

In Figure 5, there are some test cases are shown which are successfully entailed in the ontology. We have checked all 20 cases here and all cases are entailed in the ontology.

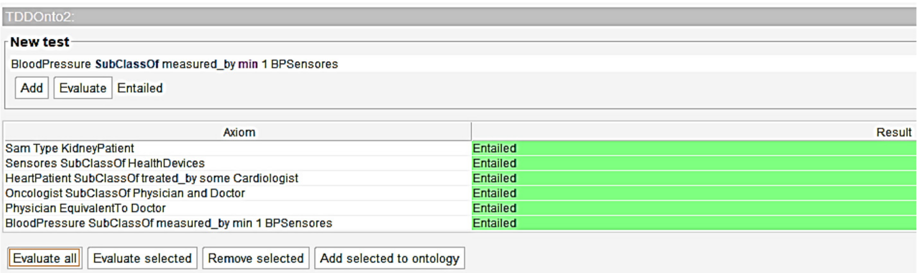


Figure 5.
Test results on TDDonto tool

4.3 Evaluation with Protégé

We have analyzed several test cases of SHC ontology on Protégé by the help of reasoner. However, this tool is not efficient as Themis and TDDonto. Some results are not found in Protégé reasoner such as: *oncologist is a subclass of Physician and Doctor*. This axiom is based on multiple hierarchies and does not found in the result. All obtained results are presented in Figure 6.

4.4 Evaluation with OOPs!

There are 41 pitfalls for analyzing the ontologies. This tool is efficient to assess the content of ontology. It analyzes the consistency, completeness, correctness, conciseness and clarity of TBox and ABox of ontology. OOPs! categorize the errors in three forms: *minor, important* and *critical*.

(1) *Critical*: these errors are must to be removed from ontologies because they could affect to reasoning, consistency and availability with others.

(2) *Important*: these errors are not critical but need to correct these pitfalls for better modeling and understanding of semantics.

(3) *Minor*: it is not an error but after removal, ontology can be presented in a better way.

This tool is best to identify the pitfalls of an ontology but not suitable to correct the problems. Pitfalls should remove by the ontology developer. These pitfalls cover criteria based evaluation (Mishra and Jain, 2018) and focuses on several criterions such as.

4.4.1 Completeness. It is checked on two levels TBox level and ABox level. In TBox (schema level), a data set is complete if it consists all of the attributes required for an assigned task. In ABox (instance level), a data set is complete if it consists all of the significant objects for an assigned task.

4.4.2 Conciseness. On the schema level, a data set is concise if it does not consist redundant attributes (two equivalent attributes with different name). On the instance level, a data set is concise if it does not consist redundant objects.

4.4.3 Consistency. A data set is considered as consistent if it is free of conflicting information. It assures that ontology does not have any contradiction. It also describes logical consistency, as well as formal and informal descriptions.

Test Cases	**Test Result in Protégé**
Doctor and Physician are equivalent entities	Found in: EquivalentClasses; Entity: Physician; Match: Physician EquivalentTo Doctor
Sam is a patient of Kidney Problem	Found in: ClassAssertion; Entity: Sam; Match: Sam Type KidneyPatient
Blood Pressure is measured by at least 1 device	Found in: SubClassOf; Entity: BloodPressure; Match: BloodPressure SubClassOf measured_by min 1 BPSensores
Heart Patients should be treated by some cardiologist.	Found in: SubClassOf; Entity: Sensores; Match: Sensores SubClassOf HealthDevices
Heart Patients should be treated by some cardiologist.	Found in: SubClass...; Entity: HeartPatient; Match: HeartPatient SubClassOf treated_by some Cardiologist
Oncologist can be a Doctor or Physician	*Not Found*

Figure 6.
Test result in Protégé

4.4.4 Correctness. This criterion assures that ontology acquires and represents the real world aspects correctly. A greater accuracy can be obtained by meaningful descriptions of classes, relations and individuals.

4.4.5 Clarity. Clarity presents that how ontology interprets the expected meaning of the described terms. The description of terms should be fixed and straight. Names of terms should be uncommon and understandable. The ontology should prefer a definition rather than a class description.

5. Result of smart health-care ontology assessment

The proposed ontology is assessed on multiple tools based on several tests cases and presented the test analysis as an output. All test results of ontology assessment are discussed in this section one by one.

5.1 Result with Themis

Figure 4 has shown the tests performed on Themis Web-based tool. It is required to load the URL of published ontology and then check the test cases.

5.2 Result with TDDonto

Figure 5 shown the test performed on Protége plugin TDDonto. It is required to check the test cases with this plugin and it provide "entailed," if knowledge is modeled in the ontology.

5.3 Result with Protégé

Reasoning is also a best way to perform evaluation based on competency questions. Some competency questions are framed in SPARQL and executed on a reasoner. Protégé editor has reasoner to execute the SPARQL queries as in Figure 7. Some of competency questions are given here.

CQ1. Display list of all heart patients.

CQ2. What are the different symptoms of diseases?

CQ3. What is the minimum requirement of BPSensores to measure the BloodPressure.

CQ4. Display the list of liver and kidney patient.

All competency questions are successfully executed with relevant information.

Figure 6 depicts "Not Found" for last test case as it is discussed that Protégé reasoned does not support multiple inheritance. SPARQL query also helpful to check the availability of modeled knowledge of ontology as in Figure 7.

To find and remove inconsistencies, redundancies, incompleteness, we have analyzed the designed ontology and rules for specifying the requirement. Rules are framed to explore the hidden knowledge among the entities and extracts accurate knowledge. Some rules are framed to examine the accuracy and completeness of the stored knowledge in SHCO. These rules are successfully executed on Drools engine and shown in Figure 8.

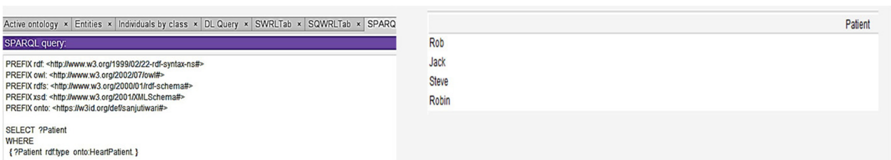


Figure 7.
SPARQL query for reasoning

5.4 Result with OOPs!

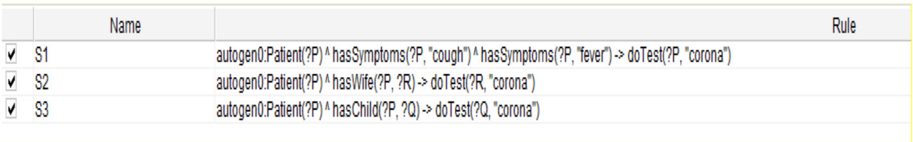
We have evaluated SHC ontology on OOPs! and found only one minor pitfall: P22 that is not considered as a problem. It is just a recommendation to follow the naming conventions for the TBox and ABox in ontology. This pitfall is shown in Figure 9 in the result section.

6. Discussions

In Table 4, a summarized result has presented with total no of tests that performed on each tool. Only one test is failed in Protégé tool because this tool is specific for ontology development and not supported to multiple inheritances. One pitfall occurs in OOPs! tool that is caused by different naming conventions in the ontology. This pitfall is a minor warning and successfully removed by following the common naming convention in the ontology.

After framing all tests, they are assessed on evaluation tools to check if there is any test that is not passed by the tools successfully. Table 4 presents the report of performed tests in all tools, all tests are successfully passed. After assessing the proposed ontology with the help of assessment tools it is successfully published on Linked Data and can be accessed by the link (http://w3id.org/def/sanjutiwari). The published ontology has been shown in 10. As several existing ontologies are analyzed in conducted review, hence a comparison of our approach with existing ontologies is discussed in Table 5.

It is observed in Table 5, only *SHCO* has been evaluated with all tools for performing complete assessment of ontology quality. During the assessment of ontology, it is found that some tools have few limitations too such as Protégé does not support multiple inheritance, TDDonto is an offline plugin to check TBox and ABox and comparatively faster, but test



	Name	Rule
✔	S1	autogen0:Patient(?P) ^ hasSymptoms(?P, "cough") ^ hasSymptoms(?P, "fever") -> doTest(?P, "corona")
✔	S2	autogen0:Patient(?P) ^ hasWife(?P, ?R) -> doTest(?R, "corona")
✔	S3	autogen0:Patient(?P) ^ hasChild(?P, ?Q) -> doTest(?Q, "corona")

Figure 8. SWRL rules for reasoning

Table 4. Summarized results of all assessment tools

Tools	No. of test	No. of failed test	Pitfalls	Remarks
Themis	20	0	–	Successfully tested
TDDonto	20	0	–	Successfully tested
Protégé	20	1	–	Not supported to multiple inheritance
OOPs!	–	–	1	Removed from ontology

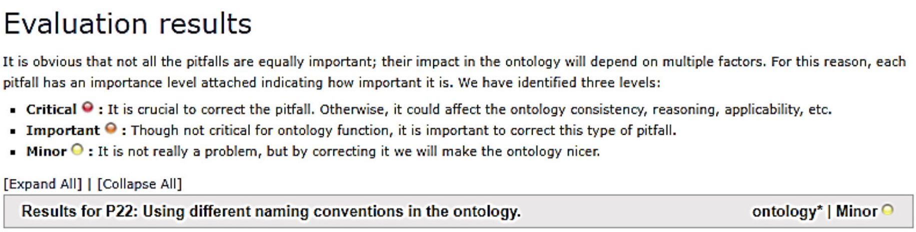
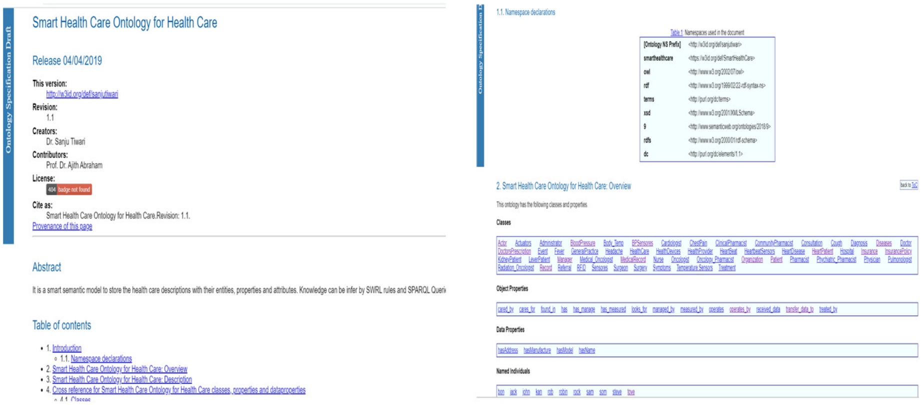


Figure 9. Result with OOPs!



(a) (b)

Figure 10.
Ontology publication

Table 5.
Comparison with existing health ontologies

Ontologies	Protégé reasoner	TDDonto	Themis	OOPs
BD	✓	X	X	X
OntoDiabetic	✓	X	X	X
HealthIoT	✓	X	X	X
SAREF4Health	✓	X	✓	✓
e-Health	✓	X	X	X
IFO	✓	X	X	X
LHR	✓	X	X	X
HealthcareIoT	✓	X	X	X
SHCO	✓	✓	✓	✓

can be done only with ontology editor as Themis and OOPs! tools are available online to check the quality of ontologies.

7. Conclusions

A quality assessment approach has been presented to analyze the quality of proposed SHCO. We have analyzed 14 assessment tools and 8 related ontologies to find best tools for assessing the SHCO. This ontology is evaluated on four offline and online tools (Themis, TDDonto, Protégé and OOPs!) for the verification and validation of modeled knowledge in ontology. Several test cases have been framed to assess on these tools. All test cases are successfully examined on these tools. SHC ontology assures that all attributes are expressed in terms of a consistent model with their classes, data types and properties. In the proposed ontology, no any unspecified terms used and it does not have unsatisfiable classes, it is found consistent when combined with data and described every classes, data types and properties. After assessing all test cases, results has been discussed and also compared with other smart ontologies in result section. After quality assessment of SHC ontology, it is successfully published on the Linked Data for the use of global community. As a future scope the ontology will be included in health related vocabularies to make it public use and can be easily accessed by Linked Open Data Cloud.

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