

**ONTOLOGY EVALUATION APPROACH
FOR SEMANTIC WEB DOCUMENTS**

NURHAMIZAH BINTI MOHD HAMKA

UNIVERSITI TEKNOLOGI MALAYSIA

ONTOLOGY EVALUATION APPROACH
FOR SEMANTIC WEB DOCUMENTS

NURHAMIZAH BINTI MOHD HAMKA

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Science (Software Engineering)

Faculty of Computing
Universiti Teknologi Malaysia

JULY 2015

DEDICATION

For Mama and Abah.

For dear siblings, grandmothers and grandfathers, families and friends.

In loving memory of late Grandmother-Atok Yam.

Thank you for the everlasting loves.

And thank you for the never ending support and prayer.

May Allah repay your deeds with happiness and peaceful in life and here-after. You, for repeatedly asking for my thesis, thank you for the years and for your secret prayers. May Allah ease us and our loved-ones.

This journey has made me believe that...

Along with Hardship, there is Ease (Al-Inshirah,94:5-6)

God will give what you need despite for what you want. And He is the best planner. And it truly is. =)

Nurhamizah Mohd Hamka

25 Ramadhan 1436

ACKNOWLEDGEMENT

Alhamdulillah. In the Name of Allah, the Most Beneficent, the Most Merciful. For which, He is the One who own all knowledge. I, despite being a poor servant of Allah, am given the opportunity to bear tiny understanding of Ontology and the Semantic Web knowledge. Herewith, I would like to express my love and appreciation to my Mama and Abah, for their prayers, supports and for their never ending love. I would also like to dedicate this honour to my supportive siblings and my grandparents, my auntie, uncles and cousins for their support. Thank you for giving me the understanding of value of life and love. As much as Ontology becomes the backbone of Semantic Web, they are the ‘Ontology’ in my ‘Semantic Web’ of life. As for my supervisor that had gone thru thick and thins of my research life, Dr Radziah Mohamad, I am truly blessed for having such an understanding ‘Guru’ to support me during most of my ‘searching for the light’ syndrome. Your support and teaching had helps me went through this journey by Allah’s will. I would like to thank Dr Nazir, Dr Roliana and i-Soft teams for the opportunity of giving me the understanding to make use of the ontology, and to Prof Naomi for leading me to them. As for Universiti Teknologi Malaysia, thank you for providing research facilities and Zamalah scholarship support throughout my research journey. Thank you for team of Ontology Summit 2013, which you had me realized that I have lots of thing to catch up for the knowledge. Thank you En Razak, Kak Ju, Ida Khairina, Khairul, Siti Mashitah, Aishah and families for your loving support during my stay at United States. May Allah bless you with happiness and grant you His blessings. I would like to give my appreciation to my friends, Hairi, Nuraini Hidayah, Nabilah, Kak Lin, Nik Zahirah, Nurul Farahain, Puan Hidayah, Shaffikah, Deera, Brother Zabha, Brother Arda, Sister Dewi, Siti Hajar, Beatrice, Chiam, ERETSEL research group, Aeronautic Lab team, Extreme Edge team, SCJ group, fellow research mate, KDSE neighbourhood and Usrah mate that I knew during my research life. Thank you as I shall cherished every moment we spent together.

ABSTRACT

Ontology is a conceptual tool used for managing and capturing information related to domain knowledge, such as the travel, education and medical domains. Publicly available ontology repositories like Falcons and SWOOGLE enhance the growth of ontology on the Web by providing a medium for ontology developers to publish their ontologies. In order to promote ontology reuse, a suitable approach for ontology evaluation is required that deals with ontology coverage for domain representation which includes an approach for validating the ontology with a corpus of information containing terms related to domain knowledge. Since contributions in ontology evaluation were introduced in different aspects, it is important to conceptualise related information to build an evaluation approach that can help users to select ontology. This work proposed OntoUji, an ontology that conceptualises information related to ontology evaluation. From OntoUji conceptualisation, these works proceed with the development of evaluation steps that are then converted into ontology evaluation algorithms to evaluate ontology documents retrieved from selected repositories according to data-driven evaluation approach. The data-driven approach focuses on evaluating the coverage of ontology using a set of keywords provided, yet similarly involves a comparison of ontological vocabulary with a pre-defined corpus, WordNet, gained from the information retrieval approach. The evaluation is then processed using Letters Pair Similarity algorithm as the selected similarity measures technique to process the ontology coverage result. The findings showed that the OntoUji ontology conceptualization helps to define ontology evaluation steps to gain similarity result for ontology selection.

ABSTRAK

Ontologi adalah suatu alat konseptual yang digunakan bagi mengurus dan menawan maklumat mengikut domain pengetahuan seperti domain pelancongan, pendidikan dan perubatan. Repositori ontologi awam seperti Falcons dan SWOOGLE meningkatkan pertumbuhan ontologi ke dalam Web dengan menyediakan wadah kepada pembangun ontologi untuk menerbitkan ontologi mereka sendiri. Untuk mempromosikan penggunaan semula ontologi, pendekatan ontologi yang sesuai amat diperlukan berkaitan dengan liputan ontologi bagi perwakilan domain termasuklah pendekatan untuk mengesahkan ontologi dengan korpus maklumat yang mengandungi istilah-istilah berkaitan pengetahuan domain. Memandangkan sumbangan dalam penilaian ontologi diperkenalkan dalam aspek yang berlainan, penting bagi mengkonsepsikan maklumat berkaitan pendekatan penilaian yang dapat membantu pengguna memilih ontologi. Kajian ini mencadangkan pembangunan OntoUji, iaitu ontologi yang mengkonsepsikan maklumat berkenaan penilaian ontologi. Berdasarkan konsep OntoUji, kajian ini membangunkan langkah-langkah penilaian yang kemudiannya ditukar kepada algoritma penilaian bagi menilai dokumen ontologi yang diambil dari repositori terpilih menurut pendekatan penilaian berasaskan data. Kaedah berasaskan data memberi fokus kepada penilaian liputan ontologi menggunakan satu set kata kunci yang diberikan, tetapi juga melibatkan perbandingan kosa kata ontologi dengan korpus yang telah ditentukan iaitu *WordNet*, yang diperolehi daripada pendekatan mendapatkan semula maklumat. Penilaian seterusnya dijalankan dengan menggunakan algoritma *Letters Pair Similarity* yang dipilih sebagai teknik mengukur persamaan bagi memproses liputan ontologi. Keputusan menunjukkan pengkosepan ontologi OntoUji dapat membantu dalam menterjemah langkah-langkah bagi menilai ontologi untuk memperoleh keputusan persamaan ontologi bagi pemilihan ontologi.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	LIST OF ABBREVIATIONS	xiii
1	INTRODUCTION	1
	1.1 Overview	1
	1.2 Motivation	3
	1.3 Problem Statement	4
	1.4 Research Questions	5
	1.5 Objectives	6
	1.6 Scope of Research	6
	1.7 Thesis Structure	7
2	LITERATURE REVIEW	8
	2.1 Introduction	8
	2.2 Semantic Web	9
	2.3 Ontology	11
	2.3.1 Types of Ontology	12

2.3.2	Ontology Representation Language	14
2.3.2.1	Structure of Ontology	15
2.3.2.2	Manipulating Ontologies	16
2.3.3	Ontology Repositories	17
2.3.4	Frame of References	21
2.4	Ontology Evaluation	22
2.4.1	Data-Driven Ontology Evaluation	27
2.4.1.1	Similarity Algorithm Measurement	28
2.5	Comparative Evaluation of Ontology Evaluation Approaches	30
2.6	Conclusion	34
3	RESEARCH METHODOLOGY	35
3.1	Overview	35
3.2	Research Framework	36
3.3	Research Design	39
3.3.1	Literature	40
3.4	Research Activity	41
3.5	OntoUji Development	43
3.5.1	Ontology Development Methodology	44
3.5.1.1	Draft Ontology Development	44
3.5.1.2	Ontology Development on Protégé	46
3.6	Ontology Evaluation	49
3.7	Validation Process	49
3.7.1	Ontology Libraries and WordNet	50
3.7.2	Similarity Algorithm	51
3.7.3	Precision and Recall	51
3.8	Summary	53
4	ONTOUJI DEVELOPMENT	55
4.1	Introduction	55
4.2	OntoUji Development	57
4.2.1	Competency Questions	59
4.2.1.1	Information of Ontology Evaluation for Semantic Web Documents	59

4.2.1.2	Dimension of Ontology Evaluation	64
4.2.1.3	Types of Domain	64
4.2.2	Development Process	65
4.3	OntoUji Implementation	68
4.4	Summary	70
5	ONTOLOGY EVALUATION	71
5.1	Introduction	71
5.2	Overview of Evaluations Step	72
5.3	Application of Evaluation Steps	76
5.3.1	Search Synonyms of Keywords	77
5.3.1.1	Keywords Terms and Domains	77
5.3.1.2	WordNet as a Frame of References	79
5.3.2	Weight for the Keywords	81
5.3.3	Calculate Coverage of Search Keyword and Relevancy	84
5.4	Summary	87
6	RESULTS AND DISCUSSION	88
6.1	Introduction	88
6.2	Search Term Weight	89
6.3	Similarity Algorithm Result	90
6.4	Findings	96
6.5	Summary	99
7	CONCLUSION AND FUTURE WORK	101
7.1	Contribution	102
7.2	Discussion and Future Work	103
	REFERENCES	105
	Appendix A	116

LIST OF TABLES

TABLE NO	TITLE	PAGE
2.1	Examples of Information in Triples Format	15
2.2	Notation for Ontology Resource	15
2.3	Ontology Repositories	18
3.1	Research Activity	42
3.2	Sample of Ontology Requirement Specification Document (ORSB) (Suárez-Figueroa <i>et al.</i> , 2009)	45
4.1	Requirements Documentation for OntoUji Development	58
4.2	Concept Description in OntoUji Part 1	60
4.3	Concept Description in OntoUji Part 2	63
5.1	Process Flow Description	75
5.2	Example of Synonym from Input Query	78
6.1	Result of Ontology Similarity from Falcons Repository	94
6.2	Precision Recall Connecting Sample	97
6.3	Comparison of Rank with Falcons and Proposed Algorithm	99
L7	Literature of Ontology Evaluation	117

LIST OF FIGURES

FIGURE NO	TITLE	PAGE
2.1	Grouping of Ontology in Details and Generality Dimensions (Sabou, 2006)	13
2.2	Watson Ontology Web Page Display	20
2.3	Falcons Ontology Search Display	20
2.4	Semantic Web Layer Cake and Ontology Evaluation Approach Connectivity	23
2.5	ROMEIO Methodology Connection Component	24
2.6	Approach of Ontology Evaluation	25
2.7	Dimension of Ontology Evaluation Aspect	26
2.8	Connection Literature of Ontology Evaluation	31
3.1	Research Framework	37
3.2	Research Design	39
3.3	Protégé Default Page	46
3.4	Create Class Tab in Protégé	47
3.5	Create Subclass in Protégé	47
3.6	Create Properties Tab in Protege	48
3.7	Insert Inverse Properties in Protégé	48
3.8	Benchmarks of Precision and Recall for Ontology Measurement (Staab <i>et al.</i> , 2004)	53
4.1	OntoUji Ontology Conceptual View Part 1	61
4.2	OntoUji Ontology Conceptual View Part 2	63
4.3	Data Driven Validation	64
4.4	Main Class in OntoUji	66

4.5	Subclass for Main Class in OntoUji	67
4.6	OntoUji Validation in Protégé Ontology Metrics	68
4.7	Pellet Reasoner Result for OntoUji Consistency Checking	69
5.1	Work Flow of Ontology Evaluation Process	73
5.2	Process Flow	75
5.3	Travel Terms Suggestion from ONKI	79
5.4	Application of Configure WordNet and Check Synonym Steps	80
5.5	Applications of Read Ontology Documents & Call Similarity Algorithm Steps	81
5.6	Application of TF/IDF Running Process Steps	83
5.7	Example Statement	85
5.8	Comparing Pair of Character from String of Keywords	85
5.9	Application of Letter Pair Similarity Steps	86
6.1	Graph of Falcons Ontology Measure Result	95
L1	Architecture Layer Cake of Semantic Web	116

LIST OF ABBREVIATIONS

API	<i>Application Program Interface</i>
CMS	<i>Content Management System</i>
FN	<i>False Negative</i>
FP	<i>False Positive</i>
HTML	<i>HyperText Markup Language</i>
IDF	<i>Inverse Document Frequency</i>
IR	<i>information retrieval</i>
LPS	<i>Letters Pair Similarity</i>
ORSD	<i>Ontology Requirement Specification Document</i>
OWL	<i>Ontology Web Language</i>
OWL-S	<i>Ontology Web Language–Semantic</i>
POS	<i>Part-of-Speech</i>
RDF	<i>Resource Description Framework</i>
RDFa	<i>Resource Description Framework in Attributes</i>
ROMEIO	<i>Requirements-oriented Methodology for Evaluating Ontologies.</i>
SE	<i>Software Engineering</i>
TF	<i>Term Frequency</i>
TN	<i>True Negative</i>
TOVE	<i>Toronto Virtual Enterprise</i>
TP	<i>True Positive</i>
URI	<i>Uniform Resource Identifier</i>
URL	<i>Uniform Resource Locator</i>
WSDL	<i>Web Services Description Language</i>
WSMO	<i>Web Services Modelling Ontology</i>
XML	<i>Extensible Markup Language</i>

CHAPTER 1

INTRODUCTION

1.1 Overview

The Semantic Web is known for supporting the interoperation between computers and people. It is an enhancement of previous Web technologies that gives meaning to data in order to be exchanged by both parties (Berners-lee *et al.*, 2001). The Semantic Web, which is known as the “Web of data” (Berners-lee *et al.*, 2001), has the ability to support synchronisation of various information in terms of structure and usage, stored in a Web environment with the ability to manipulate the information.

The technology transformed within the Semantic Web is known as ontology, one of the backbones of the knowledge structure method. Ontology is “the backbone for Semantic Web” (Ding, 2010), where it helps to conceptualise information and gives meaning in order to enhance the reliability of information selection for the user. The term *ontology* was borrowed from the philosophical world by Gruber (1993) as “a specification of a conceptualization”. This means that ontology is used to generate *lingua franca* of information specific domain knowledge or a hybrid of various types of knowledge in single-ontology structured documents. Some of the knowledge captured is then visualised into set of relationships between concepts,

individuals, or properties to describe the focused domain knowledge in triples. Ontology has been used tremendously in various fields like the biomedical area to conceptualise large amounts of medical information and keep it standardised (Bright *et al.*, 2012; Zeshan and Mohamad, 2012). Ontologies can also be implemented in other generally related systems, such as tourism (Yu *et al.*, 2005). It shows that ontologies have been widely used in different bodies of knowledge for the representation of data.

The validation of an ontology is one of the important tasks during the development or selection of an ontology (Corcho *et al.*, 2003); in fact, the process of ontology evaluation is done simultaneously within the development of the ontology until the release phase for public use. The existing work gathered the different methods for evaluation, which depend on ontology types, the domain knowledge it represents, and the methodology used for evaluation. Some of the existing works include gold-based evaluations that aim to gain direct feedback for ontology concept representation from experts within the body of knowledge, while some validation approaches contribute to analysing the content or structure of the ontology documents, depending on reliable documents (Sabou *et al.*, 2006).

Building domain ontologies from scratch is cumbersome; reusing existing ontologies is easier. Since large numbers of ontologies are available online, this indeed values the process of validation. Whether by automatic or semi-automatic validation, the measure helps to indicate the suitability of an ontology document to be used by users in a variety of usage objectives. By helping users with the selection of the ontology to be used for their own usage, this helps increase the usage of publicly available ontologies (Kalfoglou and Hu, 2006).

1.2 Motivation

Ontologies have increasingly been published online. As a part of the Semantic Web technology that enables users to increase the interoperability between information on the Web, the backbone of information linking is within the ontology Uniform Resource Identifier (URI). In addition, users are faced with a number of ontology repositories that contain a large number of ontology documents. The search for ontologies using keywords within the repositories returns a number of ontologies in the results, which involves a certain degree of coverage measurement of the ontology. The description of the ontology coverage is not displayed within the ontology results, which makes it difficult for the users to select a suitable ontology for their own purposes.

The selection of ontology is based upon the criteria and domain knowledge required from the adopter of the ontology, the user. Ontologies have diverse objectives in terms of use, whether as reference for domain knowledge or a standard of information required for the software development life cycle for traceability requirement support (Ruiz and Hilera, 2006). Different criteria of evaluation are related to the types of measurements that could signify the criteria. Although related works on ontology evaluation have cited the difficulty to attach suitable measures to surpass ontology evaluation criteria (Vrandečić, 2009), the identification of ontological aspects could also help in identifying suitable measures.

Public access ontology repositories encourage users to access ontology selections by providing general keywords, as only users know their own types of desired ontologies. The known public access ontology repositories are SWOOGLE, Falcons, and Watson. There are several known repository lists in the review by d'Aquin and Noy (2012). Noy *et al.* (2005) stated that users determined most of the ontology rankings by popularity of use, but there is an issue on the credibility of users that rank the attached ontology documents. Ontology search engines like SWOOGLE rank ontologies using the PageRank algorithm (Roger, 2002), but the search results do not state the description of the ontology documents, and the

availability of the ontologies is questionable. Some return unavailable ontologies (Farrag *et al.*, 2013).

It is known that building ontologies from scratch is considered a large effort (Kayed *et al.*, 2008), hence reusing existing ontologies is more appealing. However, selecting a suitable ontology requires proper evaluation methods. In terms of keyword search ontology methods, the relevant approach in this process leads to the data-driven approach of evaluation. In addition, content-based evaluations (Jones and Alani, 2006) work as indicators of the coverage of ontology documents for a specific body of knowledge. It requires the ontology content to include relevant keywords that represent the domain of the covered services.

1.3 Problem Statement

The search for ontologies from the Web requires the users to provide relevant keywords that might match the vocabulary of the ontology, whether on concept matching or instance matching. Users could have a problem selecting a suitable ontology because of the large numbers of ontologies published in the search results (Fahad and Qadir, 2008; Noy *et al.*, 2013; Tartir *et al.*, 2005). The limitations of viewing the ontology description make it difficult for the user to select the ontology. The description of the ontology can be included during the development of the ontology by inserting <Description> tags with information that can be manipulated for viewing in the ontology repositories. Yet, some ontologies do not include description tags.

Apart from the vast numbers of available ontologies, the issue faced by most users is the suitability of the ontology to fit their requirements (Fahad and Qadir, 2008; Gangemi *et al.*, 2005; Gómez-pérez, 2001; Oh and Yeom, 2012; Sabou, 2006; Staab *et al.*, 2004; Tartir *et al.*, 2010). Moreover, ontologies aim to be reused. The necessary criteria must be identified first since the methods of evaluation depend on

the objectives of the selected criteria. As ontologies are used for numerous purposes, diverse kinds of evaluations are required (Gómez-Pérez, 2001).

Selection of ontologies from publicly available ontology repositories require parts of the ontology to match the keyword search input provided by the user. In addition, the relevancy of the ontology is also required as part of the selection process, as the ontology document must include relevant terms from the provided keywords. In order to select a suitable ontology that covers the domain knowledge required from the search process, the main research question of the above research gap is identified as:

“How to improve ontology evaluation based on coverage selections in the Semantic Web?”

1.4 Research Questions

The research study reviews the following research questions, which signify the above objectives of findings.

- RQ1: What are the proposed evaluation approaches to evaluate ontologies in the Ontology Web Language (OWL) file format for a Semantic Web document?
- RQ2: What are the components of highlighted information during the evaluation of an ontology for a Semantic Web document (Staab *et al.*, 2004)?
- RQ3: What are the requirements and criteria objectives to be achieved regarding the evaluation of a domain ontology for a Semantic Web document?
- RQ4: How to design an algorithm to evaluate domain ontologies based on the requirements and criteria objectives that are identified?

1.5 Objectives

The aim of this research is to propose an enhanced approach for the evaluation of domain ontology coverage for Semantic Web documents. The details of the objectives are as follows:

1. To propose ontology for evaluating ontologies in the OWL file format for Semantic Web documents.
2. To evaluate ontologies using steps to select ontology for Semantic Web documents.

1.6 Scope of Research

Ontology evaluation aims for coverage criteria to ensure that the selected ontology includes domain knowledge contained in the ontology documents; therefore, the similarity string algorithm and proper corpus reference documents are needed for measuring ontological document coverage in the selected domain for ease of ontology selection for Semantic Web documents. This research proposes to validate ontologies via vocabulary aspects by proposing a similarity algorithm. The aim is to measure the matching of ontology content with a list of terms from a corpus as frames of reference.

Coverage is the main criteria of measurement for ontology validation consisting of similarity measurements from a list of terms with triples within ontology documents. The ontology focused on the selection of ontology in the Semantic Web is on OWL based ontology language during the evaluation process to support Jena and the OWL plugin to read the ontology documents downloaded from the Web. The concept and literal extraction is done to process the matching measurements with the terms, and the result gained will be validated via precision

and recall for relative comparison. This study excludes the semantic similarity measures and only focuses on the corpus or data-driven based evaluation that consists of the vocabulary aspects of the ontology.

1.7 Thesis Structure

There are various approaches and methods that provide many inputs for ontology evaluation. This chapter states the objectives to accomplish enhanced evaluation ontology approaches. The structure of the thesis is a literature study of ontologies and the evaluation approaches of the ontologies in the Semantic Web in Chapter 2. Chapter 3 describes the methodology of research in this study, and Chapter 4 describes the first objectives of this work on components of information for ontology evaluation, which are described in the form of ontology conceptual methods.

Chapter 5 describes the algorithm used to evaluate the selected ontology based on similarity measurements. Here, Wordnet (Fellbaum, 1998), an English lexical library are used as a reference for the algorithm measurements to be compared with a list of ontologies for the evaluation process. Chapter 6 entails the validation of the proposed algorithm in Chapter 5 and discusses the findings gathered from the validation process using precision and recall. The final chapter concludes the research findings and provides suggestions of improvements in future works related to the coverage criteria of evaluation in the Semantic Web.

REFERENCES

- Abdullah, N., and Ibrahim, R. (2012). Knowledge Retrieval Using Hybrid Semantic Web Search. *2012 International Conference on Computer & Information Science (ICCIS)*. 61–65.
- Abdullah, N., and Ibrahim, R. (2013). Similarity Measurement in the Hybrid of Semantic Web Search Engine. *International Journal of Computers & Technology*, 8(3), 913–921.
- Adamusiak, T., Burdett, T., Kurbatova, N., Joeri van der Velde, K., Abeygunawardena, N., Antonakaki, D., Kapushesky, M., et al. (2011). OntoCAT--Simple Ontology Search and Integration in Java, R and REST/JavaScript. *BMC Bioinformatics*, 12(1), 1–11.
- Adida, B., Birbeck, M., and Herman, I. (2011). *Semantic Annotation and Retrieval: Web of Hypertext – RDFa and Microformats*. In J. Domingue, D. Fensel, and J. A. Hendler (Eds.), *Handbook of Semantic Web Technologies* (pp.157–190, Vol. 2). Berlin, Heidelberg: Springer Berlin Heidelberg.
- Adnan, S., Shah, H., Khalid, A., Qadir, M. A., and Ali, M. (2008). OntoFetcher : An Approach for Query Generation to Gather Ontologies and Ranking Them by Ensuring User’s Context. *2008 International Conference on Emerging Technologies IEEE-ICET 2008*. 1–6.
- Alani, H., and Brewster, C. (2006). Metrics for Ranking Ontologies. *Evaluating Ontologies for the Web Workshop (EON2006), 15th International World Wide Web Conference, 23-26 May 2006, Edinburgh, Scotland*.
- Alani, H., Brewster, C., and Shadbolt, N. (2006). *Ranking Ontologies with AKTiveRank*. In I. Cruz, S. Decker, D. Allemang, C. Preist, D. Schwabe, P. Mika, M. Uschold, et al. (Eds.), *The Semantic Web-ISWC 2006* (pp.1–15).

- Aleman-meza, B., Halaschek, C., Sheth, A., Arpinar, I. B., and Sannapareddy, G. (2004). SWETO : Large-Scale Semantic Web Test-Bed. *16th International Conference on Software Engineering & Knowledge Engineering*. Banff, Canada 490–493.
- Allemang, D., and Hendler, J. A. (2008). *Semantic Web for the Working Ontologist : Modeling in RDF, RDFS and OWL*. *Journal of Empirical Research on Human Research Ethics (JERHRE)* (pp. Vol. 6).
- Amirhosseini, M., and Salim, J. (2011). OntoAbsolute as a Ontology Evaluation Methodology in Analysis of the Structural Domains in Upper, Middle and Lower Level Ontologies. *2011 International Conference on Semantic Technology and Information Retrieval*. 26–33.
- Batres, R., West, M., Leaf, D., Price, D., and Naka, Y. (2005). An Upper Ontology Based on ISO 15926. In L. PuiNaner and A. Espufia (Eds.), *European Symposium on Computer Aided Process Engineering- 15*. 1543–1548.
- Beck, K. (1999). *Kent Beck's Guide to Better Smalltalk A Sorted Collection*. Cambridge University Press New York, NY, USA ©1998.
- Berners-lee, T., Hendler, J., and Lassila, O. R. A. (2001). *The Semantic Web*. *Scientific America*.
- Blake, M. B., Cabral, L., Birgitta, K., Ulrich, K., and Martin, D. (2012). *Semantic Web Services*. (B. Blake, L. Cabral, B. König-Ries, U. Küster, and D. Martin, Eds.). Berlin, Heidelberg: Springer Berlin Heidelberg.
- Bouiadjra, A. B., and Benslimane, S.-M. (2011). FOEval: Full Ontology Evaluation. *2011 7th International Conference on Natural Language Processing and Knowledge Engineering*. 464–468.
- Boyce, S., and Pahl, C. (2007). *Developing Domain Ontologies for Course Content The Development of Ontologies*. In S. Boyce and C. Pahl (Eds.), *Educational Technology & Society* (pp. 275–288, Vol. 10).
- Brank, J., Grobelnik, M., and Mladenić, D. (2005). A Survey of Ontology Evaluation Techniques. *Conference on Data Mining and Data Warehouses (SiKDD 2005)*. 166–170.
- Brank, J., Grobelnik, M., and Mladenić, D. (2007). *Automatic Evaluation of Ontologies*. *Natural Language Processing and Text Mining* (pp. 193–219). London: Springer London.

- Brewster, C., Alani, H., Dasmahapatra, S., and Wilks, Y. (2004). Data Driven Ontology Evaluation. *In Proceedings of International Conference on Language Resources and Evaluation*. Lisbon, Portugal.164–169.
- Bright, T. J., Yoko Furuya, E., Kuperman, G. J., Cimino, J. J., and Bakken, S. (2012). Development and Evaluation of an Ontology for Guiding Appropriate Antibiotic Prescribing. *Journal of Biomedical Informatics*, 45(1), 120–8. Elsevier Inc.
- Brin, S., and Page, L. (1998). The Anatomy of a Large-Scale Hypertextual Web Search Engine. *Computer Networks and ISDN Systems*, 30(1-7), 107–117.
- Buitelaar, P., Eigner, T., and Declerck, T. (2003). OntoSelect : A Dynamic Ontology Library with Support for Ontology Selection The OntoSelect Ontology Library, 3–6.
- Casellas, N. (2011). *Methodologies, Tools and Languages for Ontology Design. Legal Ontology Engineering* (pp.57–107). Dordrecht: Springer Netherlands.
- Cheng, G. (2015). *NanJing Vocabulary Repository (NJVR)*. Retrieved June 28, 2015, from <http://ws.nju.edu.cn/njvr/>
- Chisholm, R. M. (1996). *A Realistic Theory of Categories. An Essay on Ontology*. Cambridge University Press.
- Church, K. W., Gale, W. A., and Hill, M. (1999). *Inverse Document Frequency (IDF): A Measure of Deviations from Poisson*. In S. Armstrong, K. Church, P. Isabelle, S. Manzi, E. Tzoukermann, and D. Yarowsky (Eds.), *Natural Language Processing Using Very Large Corpora*, Text, Speech and Language Technology (pp.121–130). Dordrecht: Springer Netherlands.
- Colomb, R. M. (2007). *Ontology & The Semantic Web* (pp.Vol. 156). IOS Press.
- Corcho, O., Fernández-López, M., and Gómez-Pérez, A. (2003). Methodologies, Tools and Languages for Building Ontologies. Where Is Their Meeting Point? *Data & Knowledge Engineering*, 46(1), 41–64.
- Cristani, M., and Cuel, R. (2005). A Survey on Ontology Creation Methodologies. *International Journal on Semantic Web and Information Systems*, 1(2), 49–69.
- Cristani, M., and Cuel, R. (2006). *Domain Ontologies. Encyclopedia of Knowledge Management* (pp.ed. David.137–144). IGI Global.
- D'Aquin, M., and Motta, E. (2011). Watson, More Than a Semantic Web Search Engine. *Semantic Web*, 2(0), 55–63.

- D'Aquin, M., and Noy, N. F. (2012). Where to Publish and Find Ontologies? A Survey of Ontology Libraries. *Web Semantics (Online)*, 11(August), 96–111.
- Dickinson, I. (2014). *A Complete Beginner's Guide to Starting a Jena Project in Eclipse*. Retrieved March 18, 2014, from <http://www.iandickinson.me.uk/articles/jena-eclipse-helloworld/>
- Dimitrov, M., and Simov, A. (2006). *WSMO Studio Users Guide v. 1.8*.
- Ding, L., Finin, T., Joshi, A., Pan, R., Cost, R. S., Peng, Y., Reddivari, P., et al. (2004). Swoogle: A Search and Metadata Engine for the Semantic Web. *Proceedings of the Thirteenth ACM Conference on Information and Knowledge Management - CIKM '04*. New York, New York, USA 652–659.
- Ding, Y. (2010). Semantic Web: Who Is Who in the Field -- A Bibliometric Analysis. *Journal of Information Science*, 36(3), 335–356.
- Fahad, M., and Qadir, M. A. (2008). A Framework for Ontology Evaluation. *16th Intl. Proceeding of Conceptual Structures. July 2008, France. 2008*. 149–158.
- Farrag, T. A., Saleh, A. I., and Ali, H. A. (2013). Toward SWSs Discovery: Mapping from WSDL to OWL-S Based on Ontology Search and Standardization Engine. *IEEE Transactions on Knowledge and Data Engineering*, 25(5), 1135–1147.
- Fellbaum, C. (1998). *WordNet: An Electronic Lexical Database*. Cambridge, MA: MIT Press. Retrieved October 3, 2014, from <https://wordnet.princeton.edu/>
- Gangemi, A., Catenacci, C., Ciaramita, M., and Lehmann, J. (2005). A Theoretical Framework for Ontology Evaluation and Validation. *Proceedings of SWAP2005*.
- Gangemi, A., Catenacci, C., Ciaramita, M., and Lehmann, J. (2006). Qood Grid: A Metaontology-Based Framework for Ontology Evaluation and Selection. In Y. Sure and J. Domingue (Eds.), *Proceedings of EON 2006*, Lecture Notes in Computer Science. 140–154.
- Gangemi, A., Catenacci, C., Ciaramita, M., Lehmann, J., and Gil, R. (2005). *Ontology Evaluation and Validation. An integrated Formal Model for the Quality Diagnostic Task. Technical Report. Media* (pp.Vol. 3). Rome, Italy. Retrieved from http://www.loa-cnr.it/Files/OntoEval4OntoDev_Final.pdf
- García-Ramos, S., Otero, A., and Fernández-López, M. (2009). OntologyTest: A Tool to Evaluate Ontologies through Tests Defined by the User. *Lecture Notes in Computer Science (including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. 91–98.

- Glimm, B., Horridge, M., Parsia, B., and Patel-Schneider, P. F. (2009). A Syntax for Rules in OWL 2, 2009(2), 1–10.
- Gómez-Pérez, A. (2001). Evaluation of Ontologies. *International Journal of Intelligent Systems*, 16(3), 391–409.
- Gruber, T. R. (1993). Toward Principles for the Design of Ontologies Used for Knowledge Sharing. *International Journal Human-Computer Studies*. 907–928.
- Gruber, T. R. (1993). A Translation Approach to Portable Ontology Specifications. *Knowledge Acquisition*, 5(2), 199–220.
- Grüninger, M. (1996). Designing and Evaluating Generic Ontologies. *Workshop on Ontological Engineering, European Conference on Artificial Intelligence 1996, Budapest*. 1–12.
- Grüninger, M., and Fox, M. S. (1995). Methodology for the Design and Evaluation of Ontologies. *Workshop on Basic Ontological Issues in Knowledge Sharing, IJCAI-95, Montreal*. 1–10.
- Guarino, N. (1995). Formal Ontology, Conceptual Analysis and Knowledge Representation. *International Journal of Human-Computer Studies*, 43(5-6), 625–640.
- Guarino, N., and Welty, C. (2002). Evaluating Ontological Decisions with OntoClean. *Communications of the ACM*, 45(2), 61–65.
- Hartmann, J., Spyns, P., Giboin, A., and Maynard, D. (2005). Methods for Ontology Evaluation. *Knowledge Web Deliverable D*, 5–49.
- Henderson-Sellers, B. (2011). Bridging Metamodels and Ontologies in Software Engineering. *Journal of Systems and Software*, 84(2), 301–313. Elsevier Inc.
- Heß, A., Johnston, E., and Kushmerick, N. (2004). ASSAM: A Tool for Semi-Automatically Annotating Semantic Web Services ASSAM: A Tool for Web Service Annotation, 320–334.
- Horridge, M., Knublauch, H., Rector, A., Stevens, R., and Wroe, C. (2004). *A Practical Guide To Building OWL Ontologies Using The Protege-OWL Plugin and CO-ODE Tools Edition 1.0*.
- Ivanova, T. I. (2008). A Metic and Approach for Fuzzy Ontology Evaluation. *International Scientific Conference Computer Science'2008*. 822–827.
- Jean-Mary, Y. R., Shironoshita, E. P., and Kabuka, M. R. (2009). Ontology Matching with Semantic Verification. *Journal of Web Semantics*, 7(3), 235–251.

- Jepsen, T. C. (2009). Just What Is an Ontology, Anyway? *It Professional*, 11(October), 22–27. IEEE Computer Society.
- Jones, M., and Alani, H. (2006). Content-Based Ontology Ranking. *9th International Protégé Conference, 23-26 July 2006, Stanford, CA*. 1–4.
- Kalfoglou, Y., and Hu, B. (2006). Issues with Evaluating and Using Publicly Available Ontologies. *EON2006 Evaluation of Ontologies for the Web 4th International EON Workshop Located at the 15th International World Wide Web Conference WWW*. Edinburgh International Conference Center, Edinburgh, United Kingdom 1–7.
- Kayed, A., Hirzallah, N., Shalabi, L. A. Al, and Najjar, M. (2008). Building Ontological Relationships: A New Approach. *Journal of the American Society for Information Science and Technology*, 59(11), 1801–1809.
- Kehagias, D. D., Papadimitriou, I., Hois, J., Tzovaras, D., and Bateman, J. (2008). A Methodological Approach for Ontology Evaluation and Refinement. *ASK-IT International Conference*. 1–12.
- Lange, T. De. (2012). Developing an Ontology for the Online Travelling Domain. *17th Twente Student Conference on IT, June 25th, 2012, Enschede, The Netherland*.
- Li, N., Motta, E., and D’Aquin, M. (2010). Ontology Summarization: An Analysis and an Evaluation. *Evaluation*, (Iwest), 1439–1446. Retrieved from <http://oro.open.ac.uk/24693/>
- Lozano-Tello, A., Gómez-Pérez, A., and Extremadura, U. De. (2004). ONTOMETRIC : A Method to Choose the Appropriate Ontology. *Journal of Database Management*, 15(2), 1–18. Idea Group Publishing.
- Lv, Y., and Xie, C. (2010). A Framework for Ontology Integration and Evaluation. *2010 Third International Conference on Intelligent Networks and Intelligent Systems*. 521–524.
- Maedche, A., and Staab, S. (2002). Measuring Similarity Between Ontologies. (A. Gómez-Pérez and V. R. Benjamins, Eds.) *Knowledge Engineering and Knowledge Management: Ontologies and the Semantic Web*, Lecture Notes in Computer Science, 2473(1), 251–263. Berlin, Heidelberg: Springer Berlin Heidelberg.
- Martin, D., Burstein, M., Hobbs, J., Lassila, O., McDermott, D., and McDermott, D. (2004). OWL-S : Semantic Markup for Web Services, (November), 1–34.

- Martínez-Romero, M., Vázquez-naya, J. M., Pereira, J., and Pazos, A. (2012). *A Multi-Criteria Approach for Automatic Ontology Recommendation Using Collective Knowledge. Recommender Systems for the Social Web* (pp.89–103). Springer-Verlag Berlin Heidelberg 2012.
- Matthews, B., Brickley, D., and Dodds, L. (2004). Semantic Web Technologies. *Web Semantics Science Services and Agents on the World Wide Web, Tertiary Semantic Web Technologies*, 1(3), 241–260.
- Netzer, Y., Gabay, D., Adler, M., Goldberg, Y., and Elhadad, M. (2009). *Ontology Evaluation through Text Classification*. In L. Chen, C. Liu, X. Zhang, S. Wang, D. Strasunskas, S. L. Tomassen, J. Rao, et al. (Eds.), *Advances in Web and Network Technologies, and Information Management* (pp.210–221, Vol. 5731). Springer Berlin Heidelberg.
- Ning, H., and Shihan, D. (2006). Structure-Based Ontology Evaluation. *2006 IEEE International Conference on E-Business Engineering (ICEBE'06)*. 132–137.
- Noy, N. F., Alexander, P. R., Harpaz, R., Whetzel, P. L., Ferguson, R. W., and Musen, M. A. (2013). Getting Lucky in Ontology Search : A Data-Driven Evaluation Framework for Ontology Ranking. *International Semantic Web Conference 1, Volume 8218 of Lecture Notes in Computer Science*. 444–459.
- Noy, N. F., and McGuinness, D. L. (2000). *Ontology Development 101 : A Guide to Creating Your First Ontology*. Stanford Medical Informatics (SMI-2001-0880).
- Noy, N. F., Musen, M. A., and Guha, R. (2005). User Ratings of Ontologies : Who Will Rate the Raters ? *Proceedings of the AAAI Spring Symposium on Medical Informatics*, 56–63.
- O'Hara, K., and Shadbolt, N. (2005). *Knowledge Technologies and the Semantic Web. Language* (pp.1–32). Edward Elgar. Retrieved from <http://eprints.soton.ac.uk/262469/>
- Obrst, L., Ceusters, W., Mani, I., Ray, S., and Smith, B. (2007). The Evaluation of Ontologies. *Semantic Web*. 139–158.
- Oh, S., and Yeom, H. Y. (2010). User-Centered Evaluation Model for Ontology Selection. *2010 IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology*. 314–317.
- Oh, S., and Yeom, H. Y. (2012). A Comprehensive Framework for the Evaluation of Ontology Modularization. *Expert Systems with Applications*, 39(10), 8547–8556. Elsevier Ltd.

- Pak, J., and Zhou, L. (2011). *A Framework for Ontology Evaluation. Exploring the Grand Challenges for Next Generation E-Business Lecture Notes in Business Information Processing* (pp.10–18, Vol. 52). Springer Berlin Heidelberg.
- Pammer, V., Scheir, P., and Lindstaedt, S. (2006). Ontology Coverage Check: Support for Evaluation in Ontology Engineering. *Proceedings of FOMI 2006 - 2nd Workshop on Formal Ontologies Meet Industry*. 123–134.
- Poveda-Villalón, M., Suárez-Figueroa, M. C., and Gómez-Pérez, A. (2012). Validating Ontologies with OOPS! *Lecture Notes in Computer Science (including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. 267–281.
- Qiu, Q., and Xiong, Q. (2007). *An Ontology for Semantic Web Services*. In R. Perrott (Ed.), *High Performance Computing and Communications* (pp.HPCC 2007.,776–784). Springer-Verlag Berlin Heidelberg 2007.
- Qu, Y., and Cheng, G. (2011). Falcons Concept Search: A Practical Search Engine for Web Ontologies. *IEEE Transactions on Systems, Man, and Cybernetics Part A:Systems and Humans*, 41(4), 810–816.
- Roger, I. (2002). *The Google Pagerank Algorithm and How It Works*. Copyright Ian Roger. Retrieved November 29, 2014, from <http://www.sirgroane.net/google-page-rank/>
- Ruiz, F., and Hilera, J. R. (2006). *Using Ontologies in Software Engineering and Technology. Ontologies for Software Engineering and Software Technology* (pp.49–102).
- Saaty, T. L. (2008). Decision Making with the Analytic Hierarchy Process. *International Journal of Services Sciences*, 1(1), 83–98.
- Sabou, M. (2006). *Building Web Service Ontologies. SIKS Dissertation Series*. Dutch Graduate School for Information and Knowledge Systems.
- Sabou, M., and Fernandez, M. (2012). *Ontology (Network) Evaluation*. In M. C. Suárez-Figueroa, A. Gómez-Pérez, E. Motta, and A. Gangemi (Eds.), *Ontology Engineering in a Networked World* (pp.193–212). Springer Heidelberg.
- Sabou, M., Lopez, V., and Motta, E. (2006). *Ontology Selection for the Real Semantic Web: How to Cover the Queen's Birthday Dinner? Managing Knowledge in a World of Networks* (pp.96–111).

- Sabou, M., Lopez, V., Motta, E., and Uren, V. (2006). Ontology Selection : Ontology Evaluation on the Real Semantic Web. *WWW2006, May 22–26, 2006, Edinburgh, UK*.
- Salton, G., and Buckley, C. (1988). Term-Weighting Approaches in Automatic Text Retrieval. *Information Processing & Management*, 24(5), 513–523.
- Schreiber, G., and Dean, M. (2004). *OWL Web Ontology Language Reference*.
- Sheth, A. (2011). Semantics Scales Up: Beyond Search in Web 3.0. *IEEE Internet Computing*, 15(6), 3–6.
- Sicilia, M. M. A., Rodríguez, D., García-Barriocanal, E., and Sánchez-Alonso, S. (2012). Empirical Findings on Ontology Metrics. *Expert Systems with Applications*, 39(8), 6706–6711.
- Simperl, E. (2009). Reusing Ontologies on the Semantic Web: A Feasibility Study. *Data & Knowledge Engineering*, 68(10), 905–925. Elsevier B.V.
- Soysal, E., Cicekli, I., and Baykal, N. (2010). Design and Evaluation of an Ontology Based Information Extraction System for Radiological Reports. *Computers in Biology and Medicine*, 40(11-12), 900–11. Elsevier.
- Spanoudakis, G., and Constantopoulos, P. (1994). Similarity for Analogical Software Reuse : A Computational Model LANGUAGE FOR SIMILARITY COMPUTA-. In A. Cohn (Ed.), *11th Eu- Ropean Conference on Artificial Intelligence, ECAI 94*. 18–22.
- Spärck Jones, K. (2004). A Statistical Interpretation of Term Specificity and Its Application in Retrieval. *Journal of Documentation*, 60(5), 493–502.
- Spyns, P. (2010). *Assessing Iterations of an Automated Ontology Evaluation Procedure*. In R. Meersman, T. Dillon, and P. Herrero (Eds.), *On the Move to Meaningful Internet Systems, OTM 2010* (pp.1145–1159, Vol. 6427). Springer Berlin Heidelberg.
- Sridevi, K., and Umarani, R. (2014). A Novel and Hybrid Ontology Ranking Framework Using Semantic Closeness Measure. *International Journal of Computer Applications*, 87(5), 44–48.
- Staab, S. (2002). Emergent Semantics. *IEEE Intelligent Systems and Their Applications*, 17(1), 78–79.
- Staab, S., Gómez-Pérez, A., Daelemana, W., Reinberger, M. L., and Noy, N. F. (2004). *Why Evaluate Ontology Technologies? Because it Works! IEEE*

- Intelligent Systems* (pp.74–81, Vol. 19). IEEE Educational Activities Department.
- Strasunskas, D., and Tomassen, S. L. (2007). *Web Search Tailored Ontology Evaluation Framework*. In K. C.-C. Chang, W. Wang, L. Chen, C. A. Ellis, C.-H. Hsu, A. C. Tsoi, and H. Wang (Eds.), *Advances in Web and Network Technologies, and Information Management* (pp.372–383, Vol. 4537). Springer Berlin Heidelberg.
- Suárez-Figueroa, M. C., Gómez-Pérez, A., and Villazón-Terrazas, B. (2009). How to Write and Use the Ontology Requirements Specification Document. In R. Meersman, T. Dillon, and P. Herrero (Eds.), *Lecture Notes in Computer Science (including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. 966–982.
- Tartir, S., Arpinar, I., and Moore, M. (2005). *OntoQA: Metric-based Ontology Quality Analysis. 2005 IEEE ICDM Workshop on KADASH*. Retrieved from <http://people.cis.ksu.edu/~dcaragea/papers/KADASH.pdf#page=45>
- Tartir, S., Arpinar, I., and Sheth, A. (2010). *Ontological Evaluation and Validation*. In R. Poli, M. Healy, and A. Kameas (Eds.), *Theory and Applications of Ontology: Computer Applications* (pp.R. Poli et.115–130). Springer Netherlands.
- Tversky, A., and Gati, I. (1978). *Studies of Similarity*. In E. Rosch and B. B. Lloyd (Eds.), *Cognition and Categorization* (pp.Eleanor Ro.79–99). Lawrence Erlbaum; 1st edition. Retrieved from <http://www.amazon.com/Cognition-Categorization-Eleanor-Rosch/dp/0470263776>
- Viljanen, K., Tuominen, J., and Hyvönen, E. (2007). ONKI Ontology Server — Extending Legacy Systems with Ontology Mash-up Services. *English*.
- Vrandečić, D. (2009). *Ontology Evaluation*. In S. Staab and R. Studer (Eds.), *Handbook on Ontologies*, International Handbooks on Information Systems (pp.2nd ed. 20.293–313). Berlin, Heidelberg: Springer Berlin Heidelberg.
- Vrandečić, D. (2010). *Ontology Evaluation*. (S. Staab and R. Studer, Eds.) International Handbooks on Information Systems. Springer.
- Wang, X., and Halang, W. A. (2013). *Discovery and Selection of Semantic Web Services*. Studies in Computational Intelligence (pp.Vol. 453). Berlin, Heidelberg: Springer Berlin Heidelberg.

- Weber, R. (1997). *Ontological Foundations of Information Systems*. Coopers & Lybrand and the Accounting Association of Australia and New Zealand, 1997.
- White, S. (1992). *How to Strike a Match*. Retrieved August 3, 2014, from <http://www.catalysoft.com/articles/strikeamatch.html>
- World-Wide Web Consortium: Semantic Web Layer Cake (2007)*. (2007). . Retrieved July 25, 2015, from <http://www.w3.org/2001/sw/>
- Yao, L., Divoli, A., Mayzus, I., Evans, J. a, and Rzhetsky, A. (2011). Benchmarking Ontologies: Bigger or Better? *PLoS Computational Biology*, 7(1), 1–15.
- Yu, J., Thom, J. A., and Tam, A. (2005). Evaluating Ontology Criteria for Requirements in a Geographic Travel Domain. *Lecture Notes in Computer Science (including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. 1517–1534.
- Yu, J., Thom, J. A., and Tam, A. (2007). Ontology Evaluation Using Wikipedia Categories for Browsing. (M. J. Silva, A. H. F. Laender, R. A. Baeza-Yates, D. L. McGuinness, B. Olstad, Ø. H. Olsen, and A. O. Falcão, Eds.) *Proceedings of the Sixteenth ACM Conference on Conference on Information and Knowledge Management (CIKM 07)*, 223. ACM Press.
- Yu, J., Thom, J. a., and Tam, A. (2009). Requirements-Oriented Methodology for Evaluating Ontologies. *Information Systems*, 34(8), 766–791. Elsevier.
- Yu, Q., Liu, X., Bouguettaya, A., and Medjahed, B. (2006). Deploying and Managing Web Services: Issues, Solutions, and Directions. *The VLDB Journal*, 17(3), 537–572.
- Zeshan, F., and Mohamad, R. (2012). Medical Ontology in the Dynamic Healthcare Environment. *Procedia Computer Science*, 10, 340–348.