UNIVERSITI PUTRA MALAYSIA

METHODOLOGY FOR DOMAIN ONTOLOGY DEVELOPMENT WITH HUMAN-CENTERED DESIGN

RIZWAN IQBAL

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METHODOLOGY FOR DOMAIN ONTOLOGY DEVELOPMENT WITH HUMAN-CENTERED DESIGN

By

RIZWAN IQBAL

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

November 2014

DEDICATION

This thesis is especially dedicated to my wife and parents.

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Degree of Doctor of Philosophy

METHODOLOGY FOR DOMAIN ONTOLOGY DEVELOPMENT WITH HUMAN-CENTERED DESIGN

By

RIZWAN IQBAL

November 2014

Chairman: Associate Professor Masrah Azrifah Azmi Murad, Ph.D.

Faculty: Computer Science and Information Technology

Ontologies play an important role to envision the future of semantic web. Over the years, the practitioners of the field of ontology engineering to support the notion of merging different methodologies and techniques together for developing ontologies. This opens an avenue for new and different design ideas, making the ontology development process to be more effective and intuitive.

However, through literature review it was found that most existing methodologies are extreme in their preference to include domain experts in ontology development process. There is a need to bring a balance in between the two extremes, so that a broader audience should be given the opportunity to participate and contribute in the ontology development process.

Moreover, in existing literature, the notion of human centered design is neglected and there is a need to come up with methods which does not put burden on the audience for mastering them and should be easy to adapt for supporting ontology development. Furthermore, gaps related to immediate resolution to ambiguities, knowledge validation, manual selection of terms and ontology evaluation needs to be addressed. In order to bridge the aforementioned gaps, a methodology is proposed for developing ontologies using concept maps, with a focus on human centered design.

The proposed approach is devised based on shortcomings found in existing literature as well as the lessons learnt while conducting preliminary study. The proposed methodology enables a broader audience to participate and contribute in the ontology development process, while exploiting natural language as the basis of ontology conceptualization. At the same time, it supports the notion of human centered design and integrates the element of learning, discourse and human feedback during the evolution of the ontology by exploiting concept mapping technique in different phases of the proposed methodology. Moreover, a term extraction engine (application) is also

developed as a part of the methodology for automatically extracting the potential terms for concept mapping.

For evaluating the proposed methodology, a study employing the mixed methods research design was conducted in collaboration with Quran domain experts (from University of Malaya and International Islamic University Malaysia). The mixed methods approach provided an in-depth understanding of the results and findings for answering the research hypotheses related to the proposed methodology. The results manifest that all the hypotheses are proven to be true, and the notion of human centered design is found to be successfully integrated in to the ontology development process. In addition, an ontology for the domain of Quran is generated as output from the study. Furthermore, an empirical investigation was performed to carry out ontology validation to ensure that the resulting Quran ontology is a true representation of the actual domain, as defined by Quran experts. The results of this investigation manifested the calculations for Closeness index (C) = 1 and Similarity index (S) = 1, meaning that values of both measures indicate that the implemented ontology is an actual representation of the domain.

Abstrak tesis ini dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuh ikeperluan untuk Ijazah Doktor Falsafah

METODOLOGI UNTUK PEMBANGUNAN ONTOLOGI DOMAIN DENGAN REKA BENTUK BERPUSATKAN MANUSIA

Oleh

RIZWAN IQBAL

November 2014

Pengerusi: Profesor Madya Masrah Azrifah Azmi Murad, Ph.D.

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Ontologi memainkan peranan yang penting untuk membayangkan masa depan web semantik. Sejak beberapa tahun, pengamal bidang kejuruteraan ontologi menyokong tanggapan menggabungkan metodologi dan teknik yang berbeza bersama-sama untuk membangunkan ontologi. Ini membuka ruang untuk idea-idea reka bentuk yang baru dan berbeza, menjadikan proses pembangunan ontologi lebih berkesan dan intuitif. Baru-baru ini, teknik konsep pemetaan telah diselidik untuk sebab ini.

Walau bagaimanapun, melalui pernyataan masalah mendapati bahawa pendekatan yang sedia ada mengabaikan konsep reka bentuk berpusatkan manusia serta jurang yang berkaitan dalam manual pemilihan istilah, resolusi segera kepada kekeliruan, pengesahan pengetahuan, dan penilaian ontologi yang efektif perlu dicadangkan. Dalam usaha untuk merapatkan jurang yang dinyatakan di atas, metodologi yang dicadangkan untuk membangunkan ontologi menggunakan peta konsep, dengan memberi tumpuan kepada reka bentuk berpusatkan manusia.

Pendekatan yang dicadangkan direka berdasarkan kekurangan yang terdapat dalam penulisan yang sedia ada serta pengalaman yang diperoleh semasa menjalankan dua kajian kes yang berbeza. Kajian kes telah dijalankan menggunakan dua kaedah yang sahih dan juga kaedah terkenal yang sedia ada. Untuk menyokong idea reka bentuk berpusatkan manusia, kaedah yang dicadangkan mengintegrasikan elemen pembelajaran, wacana dan maklum balas manusia dalam evolusi reka bentuk ontologi. Selain itu, satu Terma Pengekstrakan Enjin (aplikasi) telah dibangunkan sebagai sebahagian daripada kaedah untuk mengekstrak secara automatik potensi terma untuk konsep pemetaan.

Untuk menilai kaedah yang dicadangkan, satu kajian menggunakan kaedah campuran telah dijalankan dengan kerjasama pakar-pakar domain Quran (dari Universiti Malaya dan Universiti Islam Antarabangsa). Pendekatan kaedah campuran menyediakan pemahaman yang mendalam tentang keputusan dan penemuan untuk menjawab

hipotesis penyelidikan yang berkaitan dengan kaedah yang dicadangkan. Keputusan menunjukkan bahawa semua hipotesis terbukti benar dan reka bentuk bertumpukan manusia didapati berjaya diintegrasikan di dalam proses pembangunan ontologi. Di samping itu, ontologi bagi domain Quran turut dihasilkan sebagai output daripada kajian yang dijalankan. Selain itu, penyelidikan empirikal dilakukan untuk pengesahan ontologi bagi memastikan ontologi Quran yang dihasilkan adalah gambaran sebenar seperti mana ditakrifkan oleh pakar-pakar Al-Quran. Hasil keputusan ini menunjukkan pengiraan indeks kedekatan (C) =1 dan indeks persamaan (S) =1 membawa maksud kedua-dua nilai ini menunjukkan ontologi yang dilaksanakan adalah perwakilan domain yang sebenar.

.

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Pursuing a Ph.D. project is a both painful and enjoyable experience. It is just like climbing a high peak, step by step, accompanied with bitterness, hardships, frustration, encouragement and trust and with so many people's kind help. When I found myself at the top enjoying the beautiful scenery, I realized that it was, in fact, teamwork that got me there. Though it will not be enough to express my gratitude in words to all those people who helped me, I would still like to give my many, many thanks to all these people.

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I am very grateful to my mother. Her understanding and her love encouraged me to workhard and to continue pursuing a Ph.D. project abroad. Her firm and kind-hearted personality has affected me to be steadfast and never bend to difficulty. She always lets me know that she is proud of me, which motivates me to work harder and do my best.
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She took every responsibility and suffered all the bitterness to take care of my daughters and my family. Even when my wife and daughers were ill, she would not let me know so as to enable me to concentrate on my research. I owe my every achievement to my wife. I salute her for her endless love and dedication to me.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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I hereby confirm that:

- this thesis is my original work;
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Signature: ______________________ Date: ____________________

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LIST OF ABBREVIATIONS

CG	Conceptual Graph
ISO	International Organization for Standardization
IEEE	Institute of Electrical and Electronics Engineers
KM	Knowledge Management
KSE	Knowledge Sharing Effort
NLP	Natural Language Processing
OWL	Web Ontology Language
ORSD	Ontology Requirements Specification Document
OE	Ontology Engineering
OWL-DL	Web Ontology Language-Description Logic
p-value	Probability value
POS	Part Of Speech
QUAL	Qualitative Research
QUAN	Quantitative Research
RDF	Resource Description Framework
SUO	Standard Upper Ontology
SRS	Software Requirements Specification
UP	Unified Process
UML	Unified Modeling Language
W3C	World Wide Web Consortium
XML	Extensible Markup Language

CHAPTER 1

INTRODUCTION

1.1 Background

Ontologies have been discussed for centuries in philosophy, they describe ontology as "the study of being or existence" (Cahn, 2012; Simperl, 2009). In computer science, ontologies are being extensively used in the fields of knowledge management, information retrieval, natural language processing, e-Commerce, information integration, e-learning, database design, geographical information systems and many other areas. They are considered as essential parts of intelligent information systems, where they are utilized by knowledge engineers to come up with problem solving approaches and reasoning services.

Ontology is a declarative piece of knowledge which can be reused as well as shared. They are an effective way to share and disseminate knowledge. Most importantly, these structures of knowledge are machine understandable and machine readable in nature. Although ontologies have been used commonly in distinct fields and areas, its definition, purpose and characteristics also slightly vary from field to field.

The importance and significance of ontologies today in the field of computer science cannot be denied. They play an important role to envision and materialize the vision of the Semantic Web which was introduced by Tim Berners Lee (Berners-Lee., 2001).

1.2 Semantic Web

The World Wide Web is exploded with information and at times the required information cannot be explored by search engines. Semantic web, also known as 'Web of Data', addresses this issue by offering formalisms for data markup which can be processed and understood by machines. This allows meaningful information to be reached, without any barriers.

The W3C ("W3C Website," 2014) describes as follows: "The Semantic Web provides a common framework that allows data to be shared and reused across application, enterprise, and community boundaries."

The notion of semantic web is to introduce a new structure to the current web. The semantic web, also known as Web 3.0 is different from Web 1.0 and Web 2.0 ("Sizlopedia Website," 2014). The Web 3.0 gives more importance to data, unlike the present web which is based on documents.

Figure 1.1 and Figure 1.2 represent the working of Web 1.0 and Web 2.0, respectively.

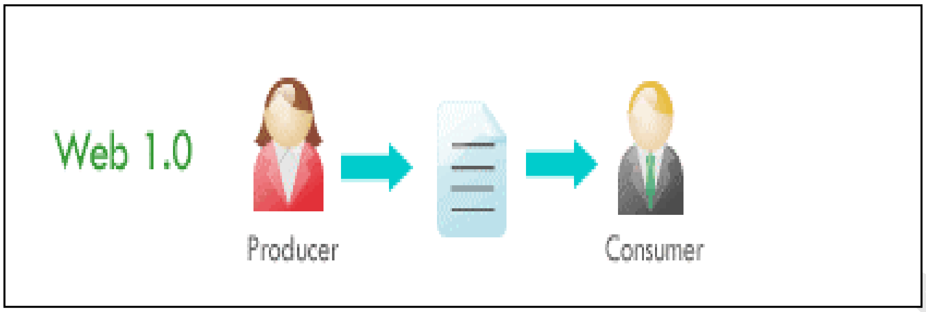

Figure 1.1 Web 1.0, the web of documents (human-readable web)

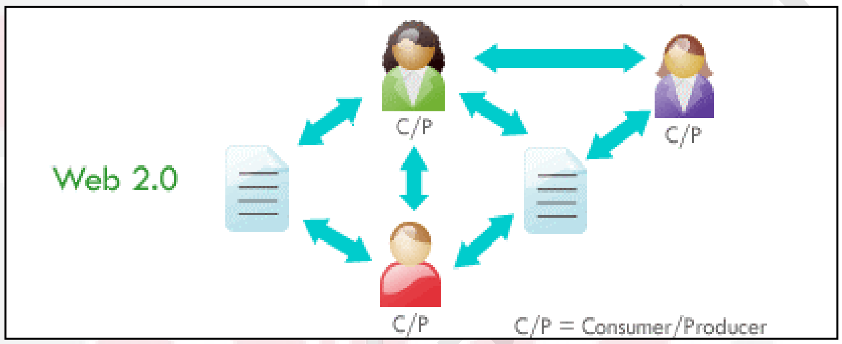

Figure 1.2 Web 2.0, the web of people

The notion of semantic web is to introduce a new structure to the current web. The semantic web is based on a layered framework. The lower layers of the framework deals with XML (Bray et al., 1998), RDF (Klyne & Carroll, 2004) and OWL (McGuinness et al., 2004). All these languages can be effectively used to describe structures of knowledge in a machine understandable format. Therefore, ontology is an important component of semantic web which empowers machines to understand the data (Islam & Shaikh, 2010).

1.2.1 Definitions of ontology

Several definitions for ontology have been defined to date with the motivation to clarify the meaning of ontology in the field of computer science and Artificial Intelligence. Some of the selected definitions are as follows:

Definition 1. According to Neches et al (1991) ontology is a kind of "top-level declarative abstraction hierarchies" "represented with enough information to lay down the ground rules for modeling a domain. Ontology defines the basic terms and relations comprising the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary."

This definition was based on experience attained during the DARPA Knowledge Sharing Effort (KSE). The project had the motivation to share and reuse the existing ontologies for different systems. It helped to cut down building costs and also promoted ontology reuse.

Definition 2. Gruber who was also part of the Knowledge Sharing Effort (KSE) team investigated further to find the answer to “what can be done to enable the accumulation, sharing and reuse of knowledge bases?". He came up with the definition that ontologies are “vocabularies of representational terms – classes, relations, functions, object constants – with agreed-upon definitions in the form of human readable text and machine-enforceable, declarative constraints on their well-formed use” (Gruber, 1991). His definition further added more description like domain ranges and axioms.

Definition 3. Another definition discusses about the inspiration which computer science took from metaphysics over the passage of time. Musen (1992) states that "computer scientists have co-opted from their colleagues in metaphysics the term ontology to describe formal descriptions of objects in the world, the properties of those objects, and the relationships among them. An ontology thus has at its root a standardized lexicon, but includes additional information that defines how objects can be classified and related to one another”.

Definition 4. Ontologies can also be exploited for the purpose of describing the structure of knowledge bases. Therefore, representing the commitments during the modeling phase for the sake of promoting knowledge sharing. According to B. J. Wielinga & Schreiber (1993) "a theory of what entities can exist in the mind of a knowledgeable agent."

Definition 5. Having a different point of view, Alberts (1994) stresses upon the importance of creating ontologies, where concepts should be both general and specific enough in nature to fully cater the task at hand. He mentions, "One of the major problems in modeling design knowledge is finding a useful set of concepts that the knowledge should refer to, or, in more fashionable terms, an ontology. These concepts should be general enough for describing different types of design knowledge in different design domains, but specific enough to do justice to the particular nature of the task at hand: the design of technical systems. This ontology should serve as the basis for a formal description of the knowledge involved in such a task"

Definition 6. According to Lassila & McGuinness (2001) “An explicit specification of a conceptualization an ontology that has the following properties: (1) a finite controlled vocabulary, (2) an unambiguous interpretation of classes and term relationships and, (3) a strict hierarchical subclass relationships between classes”.

Most of the definitions are based on inspiration from each other or as a result of criticism on the existing definitions. There might be as many definitions for ontology, as their purpose of creation and utilization. Therefore, there is no one correct definition of ontology. It depends on the context, it is being referred.

However, in the case of this thesis, definition by Lassila & McGuinness (2001) is adopted and whenever the term ontology occurs it should be interpreted according to their definition.

1.2.2 Types of ontology

Ontologies can be classified into different types. Different researchers came up with different categorizations based on their distinct criteria's (Asunción Gómez-Pérez et al., 2004). Based on the level of dependence on a particular task or point of view, ontologies can be categorized into 4 categories: top-level ontology, domain ontology, task ontology and application ontology. Figure 1.3 represents the four categories based on their level of independence.

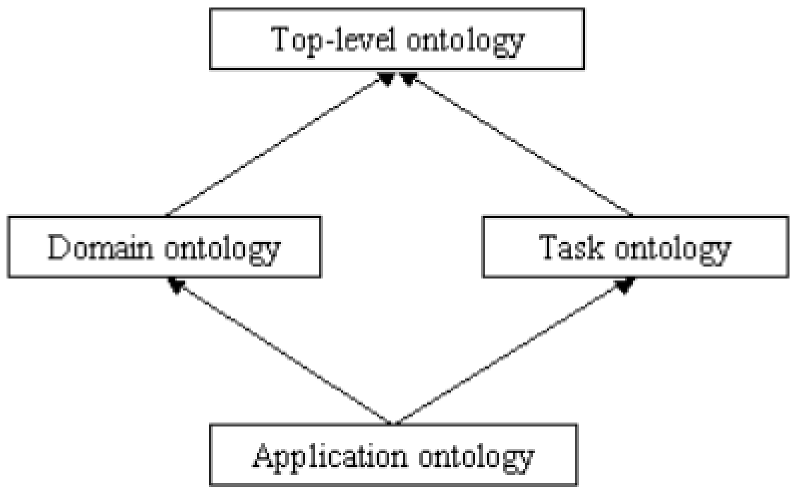

Figure 1.3 Four categories of ontologies

Top / Upper level ontology

These ontologies are very general in nature. Their concepts and notations are so general in nature that all the root terms in existing ontologies should be linked to them. However, the main problem with these ontologies is that there are many of them available and all of them follow a different criterion for classifying the concepts in the ontology hierarchy. In order to address this issue, an initiative has been taken in the form of defining the IEEE Standard Upper Ontology (SUO) to come up with a standard upper ontology. This ontology recommends developing domain ontologies using general concepts from it.

Domain ontology

These ontologies provide a specific vocabulary about the concepts and relationships, theories and elementary principles belonging to a particular domain (medical, engineering, tourism, geography, and gene). These ontologies can also be reused for their respective domains. There is a clear distinction between domain ontologies and upper-level ontologies. The concepts used in domain ontologies are usually more domain specific in nature, in other words they are specializations of concepts defined in top-level ontologies. They can be utilized for various purposes.

Task ontology

These ontologies encapsulate vocabulary related to a task or activity that is generic in nature. They are built using specialized terms from top-level ontologies. They can focus to define any task or activity like scheduling, buying, selling, production, and quality control. Task ontologies are not domain specific, they can be used to address problems that may or may not relate to a particular domain.

Application ontology

These ontologies are application dependent. They are specifically tailored to encapsulate all the definitions required to represent the knowledge required for a particular application. The vocabulary represented in these categories often extends and specialize the vocabulary of both, the domain and task ontologies for a specific application.

1.2.3 Ontology engineering

Due to constantly growing interest in ontologies over the years, many practitioners of the field came up with different approaches for building ontologies. Mostly these methodologies focus to address the knowledge acquisition bottleneck within the ontology development process.

Until the middle of the 1990s, engineering ontologies was more like an art rather than an engineering activity. This was due to the fact that there was an absence of structured guidelines and each development team usually followed their own set of guidelines and design criteria for building ontologies (Asunción Gómez-Pérez et al., 2004).

After the mid-1990s initiatives were taken in the form of international conferences and seminars, where researchers got a platform to share their principles, design decisions and good principles for building ontologies. This was the starting point for the field of ontology engineering to catch attention from researchers all over the globe.

Ontology engineering is the discipline that particularly explores the methodologies, approaches and tools employed for developing and editing ontologies. An ontology engineering methodology provides a set of guidelines or techniques to assist the knowledge engineers and domain experts during all phases of ontology development.

However, an important issue in the existing literature is that the terms methodology, method, technique, process and activity are often used interchangeably and loosely which creates ambiguity (Asunción Gómez-Pérez et al., 2004).

In the last decades several methodologies have been proposed. Apart from differences with respect to level of details and the effectiveness of the techniques employed, most of the approaches propose the following development oriented activities for developing ontologies (Gomez-Perez., 2004).

Requirements analysis

This includes analysis of the domain to be modeled. This phase gather down the requirements which the ontology should meet. In other words, describing the capabilities which the implemented ontology should satisfy. It also includes performing some knowledge acquisition activities including, reusing of existing ontologies, exploring existing sources of knowledge and performing ontology learning activities. Usually some techniques are employed in this phase as a result of which an ontology requirements specification document or a criterion is defined.

Conceptualization

As the name suggests, this phase focuses on conceptualizing the target domain. The development team models the target domain in terms of ontological primitives including, concepts, relationships and axioms. The output of this phase is a conceptual model which is language independent in nature and could be transformed to a specific knowledge representation paradigm.

Implementation

This phase deals with the implementation aspect of the conceptual model, which was the final output from the previous phase. Issues related to selection of a formal representation language, choosing the appropriate implementation tool, and heuristics related to transforming the conceptual model are catered in this phase. The output of this phase is an implemented working ontology.

Evaluation

The goal of this phase is to evaluate the implemented ontology against the requirements or specifications for which it was intended to satisfy. The evaluation can be performed automatically, semi automatically or manually, depending on the preference of the team as well as the nature of the domain being modeled. Evaluation can result in modification or refinement in the implemented ontology.

Evolution or maintenance

This phase may come after evaluation, if needed. It deals with making further modifications in the ontology to adapt new user requirements, or reflecting changes occurring in the domain being modeled in the ontology.

1.3 Motivation of Study

In the last two decades, ontologies have gained significant attention in the research world. This is due to the fact that in the present day, they are extensively used in different domains like knowledge engineering, artificial intelligence, natural language processing, e-commerce, intelligent information integration, and information retrieval. Based on the constantly increasing popularity and need for ontologies, several methodologies have been proposed to date for facilitating the ontology development process.

In the pursuit of bringing improvement in the ontology development process the practitioners of the field have supported the notion of merging different methodologies and techniques together. This opens an avenue for new and different design ideas, making the ontology development process more effective (Brusa et al., 2008; Spyns et al., 2008).

It is evident in literature that over the years ontology engineering have significantly inclined towards collaborative ontology development (Simperl et al., 2010). Some recent approaches can be found in literature which follow this trend (Holsapple & Joshi, 2002; Vrandecic et al., 2005; Kotis & Vouros, 2006; Spyns et al., 2008; Ghidini et al., 2009; Sua et al., 2012). However, through literature review some gaps have been indenfied in the following paragraphs, if addressed can lead to improvement in the ontology development process.

1.4 Problem statement

Most existing methodologies seem rather extreme in their preference to include domain experts as identified by Ongenae et al (2011). Some approaches consider domain experts involvement only in a part of the ontology life cycle, for instance, during the specification or validation phase. On the other hand, some approaches facilitate the domain experts with user friendly and collaborative tools to build ontologies completely on their own. There is a need to bring a balance in between the two extremes so that a broader audience (including ontology engineer, domain experts, project stakeholders and users) should be given the opportunity to participate and contribute in the ontology development process.

In the existing literature recommendations are often found that the domain experts should not be bothered with how to think in a formal language (Spyns et al., 2008). Similarly, a down to earth method must be devised for ontology conceptualization because the domain experts (as well as other participants, including, project stakeholders and users) have no primarily practical skills and experience whatsoever in modelling (Spyns et al., 2008). However, it has been found that recently proposed methodologies, like NeOn (Sua et al., 2012) does not include any guideline for non-experienced domain experts for ontology development (Stadlhofer et al., 2013). Therefore, there is a need to introduce techniques which does not put burden on domain experts for mastering them and should be easy to adapt (Stadlhofer et al., 2013).

Moreover, it is learned from the conducted preliminary study that use of natural language helps to clearly define the requirements specification and scope for all people including domain experts and non domain experts. This finding is also in alignment with recommendations found in existing literature that natural language acts as a starting point and further acts as a elicitation vehicle for the modelling process (Meersman, 2001). Furthermore, it is recommended that a method should have the semantics described and rooted in natural language; otherwise users can not reach a consensus on common semantics (Meersman, 2001; Spyns et al., 2008). Stadlhofer et al (2013) also mentioned that there is need to reduce the complexity found in ontology engineering activities as it can result in loosing motivation towards modeling.

International standards such as ISO 9241-210 (DIS, 2010) describes human centered design as "an approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques". Human centered design has its root deep in to discourse, learning and cognition. It is a notion in which the needs, wants, and limitations of users of a product, service or process are given extensive attention throughout the design process.

Based on the problem statements and recommendations identified in existing literature, as well as the lessons learned from preliminary study; hence there is a need to inculcate the notion of human centered design in to the ontology development process in conjunction with the use of natural language. The adopted technique should serve effectively for the purpose of engaging a broader audience (domain experts and non-domain experts) to participate and contribute in the ontology development process while exploiting natural language as the basis of ontology conceptualization. Moreover, the participants should be given opportunity to interact with the conceptualization in a direct mode, as suggested by (Kotis & Vouros, 2006).

1.5 Research Questions

This research posits the following research questions:

• How to bring a balance in between the two extremes for engaging domain expert in the ontology development process assuring that a broader audience participate and contribute during ontology development?

• Whether the techniques employed to inculcate the notion of human centered design coupled with the use of natural language have certain characteristics. For instance, does it require prior skills by the participants? Is it easy to implement? Does it help to resolve conflicts and ambiguities on immediate basis? Do the participants experience learning?

• How to validate that the developed ontology is a correct representation of the domain being modeled?

1.6 Research Objectives

• To propose a methodology for ontology development that enables to bring a balance by enabling a broader audience to participate and contribute during the ontology development process. The methodology should introduce the essence of human centered design coupled with use of techniques based on natural language.

• To evaluate a set of hypotheses related to the proposed ontology development methodology. This will allow validating theoretical propositions related to its characteristics.

• To empirically investigate that the ontology validation process enables to determine the correctness of the developed ontology.

1.7 Research Propositions/Hypotheses

A set of hypotheses are devised to validate certain characteristics of the proposed methodology which helps to demonstrate that how well the proposed methodology adopts the notion of human centered design and addresses the gaps found in the problem statements (Section 1.4).

Hypothesis 1: The employed technique in the methodology effectively defines the requirements and scope of the ontology to be developed.

Hypothesis 2: The term extraction engine (application) helps to reduce development time and efforts.

Hypothesis 3: Concept mapping is easy to learn.

Hypothesis 4: Concept maps are comfortable to create.

Hypothesis 5: During conceptualization learning is experienced by the participants.

Hypothesis 6: During conceptualization conflict of opinions and term ambiguities are resolved on immediate basis.

Hypothesis 7: Participants get a chance to input their feedback during the evolution of the ontology design.

Hypothesis 8: Knowledge validation allows an individual to test his/her understanding about the ontology design.

Hypothesis 9: The tabular output helps to get a quick insight about the ontology design details.

Hypothesis 10: Evaluation process is useful in assessing compliance of the implemented ontology with its requirements.

1.8 Research Scope

The aim of this research is to propose an ontology engineering methodology for developing ontologies with a focus on human centered design. Therefore, we have defined the research scope as follows:

The proposed methodology is meant for developing domain ontologies. It covers all phases from requirements to implementation and validation.

The proposed methodology is based to developing an ontology in a collaborative setting, where domain experts are at least a proportion of the participants. The other categories of participants include the ontology engineer, project stakeholders and users.

The study will be focused to examine a set of hypotheses based on the proposed methodology.

1.9 Research Contributions

The contribution of this research is considered from both theoretical and practical terms. The primary contribution of this research lies in the proposed ontology development methodology, which enables to collaboratively develop ontologies accompanied with the notion of human centred design coupled with techniques based on natural language. The proposed methodology merged different techniques together to make the ontology development process more effective.

The concept mapping technique is integrated in a way to develop ontologies in a collaborative environment, as it is the latest trend in ontology development (Simperl et al., 2010). It provides the following benefits: a mechanism for reducing ambiguities, enhances the understanding of the ontology scope at the modeling level, to foster learning, and for propagating homogeneity and coherence in the way the team perceives the part of the world being modeled.

Moreover, the proposed technique for knowledge validation allows the participants to validate their knowledge regarding the ontology design before being implemented. It eliminates the likeliness of mistakes, ambiguities or lucky guesses. For ontology evaluation, the methodology proposes to perform both formal and graphical level validation to make the evaluation process more robust.

A term extraction engine (application) is also developed for facilitating the extraction activity of potential candidate terms from the text. Part Of Speech (POS) tagging coupled with pattern-based extraction techniques are opted (Hearst, 1992). The application makes use of some existing patterns as well as some new patterns for performing extraction. The developed engine has been copyrighted and available for distribution.

A study employing the proposed ontology engineering methodology was conducted. The study opted a mixed methods research design which employs both quantitative and qualitative methods. It was designed to test a set of hypotheses (Section 1.7) related to characteristics of the proposed methodology, using non-parametric statistics. For the quantitative part, a close ended questionnaire was used to get response from the participants engaged in the study. For the qualitative part, observations and interviews helped to further validate the hypotheses and attain deep insight about the distinct aspects of the proposed methodology.

As a result of the performed study an authentic Quran ontology was developed. The developed Quran ontology provides contextual information related to the Quran. It encapsulates Quranic exegeses (tafsir) and dual translation in English and Malay, for correct interpretation. The ontology can be used as core knowledge base for a dialogue-based information visualization system or any other semantic applications in the future. The ontology design is flexible, it can be extended and modified as per need. The Quran ontology has been copyrighted and available for distribution.

1.10 Thesis Organization

This thesis adheres to the format of thesis and dissertations at University Putra Malaysia. It is organized in a manner to give detailed information on how the research is executed. The thesis is organized in into 7 chapters and the summary of each chapter is mentioned below.

Chapter 1 (Introduction)

This chapter introduces the background of research. It includes the researcher's motivation which is followed by the problem statements, research questions and research objectives, respectively. The scope of research and the contributions resulting from this research are also explained in this chapter.

Chapter 2 (Literature Review)

This chapter presents a review of ontology engineering methodologies. The chapter includes concluding remarks highlighting the shortcomings in existing methodologies. Most importantly, it is reported that most existing methodologies are extreme in their preference for domain experts. Therefore, a balance or middle ground should be adopted, so a broader audience should be engaged and interactive during ontology development. Moreover, it is important to adopt methods which provide direct manipulation of conceptualizations, supported with continuous learning, argumentative support and ambiguity resolution. The chapter ends with suggestions regarding the adoption of human centered design and concept mapping technique based on the concluding remarks.

Chapter 3 (Research Methodology)

This chapter cover details of the research methodology design opted for this research. It describes the phases and steps of the research process. The details regarding research hypotheses, techniques for data collection, development of questionnaire, data collection, pilot study, instrument validity and reliability and sample size. The chapter also highlights details of the unit of analysis and the method of analysis for data analysis purpose. The process for performing ontology validation after implementation is also covered in this chapter.

Chapter 4 (Preliminary Study)

This chapter presents details of two case studies which were conducted with the motivation to attain further insight into the ontology development process and practically experience limitations found in the existing two methodologies. Some highlights from the lessons learnt section include that the use of natural language helps to clearly define ontology requirements and scope for all, including domain experts and non domain experts. Moreover, manual identification of terms (concepts, instances, relationships) to be used for formalizing the ontology can be time consuming.

Chapter 5 (Proposed Ontology Engineering Methodology)

This chapter presents the proposed ontology engineering methodology. It discusses the details of the proposed methodology, including necessary background and a preliminaries section. It explains the processes and their respective activities involved in the ontology development process. Furthermore, the chapter describes the working, architecture and user interface details of the term extraction engine application which facilitates in the term extraction process. Finally, the chapter summarizes with highlighting the key features of the proposed approach.

Chapter 6 (Results and Discussion)

This chapter presents the research findings accompanied with relevant discussions. It includes results of the instrument (questionnaire) validity and reliability analysis, and results of the hypotheses testing, based on both quantitative and qualitative evidence. In addition, the novelty of the Quran ontology is explained (output from the conducted study, including the empirical results for ontology validation.

Chapter 7 (Conclusion and Future Work)

This chapter summarizes the main ideas of the thesis. It highlights both the theoretical and practical implications from this research. In addition, the research limitations and potential directions for future work are covered.

1.11 Chapter Summary

The central goal of this thesis is to develop an ontology engineering methodology with a focus on human centered design. This chapter briefly covers different definitions of ontology, types of ontologies and basics of the field of ontology engineering. Then the motivation of study is described followed by the problem statement. After that, the research objectives and research hypotheses are mentioned which leads to contributions arising from this research. Finally, the chapter ends discussing the thesis outline.

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