Designing an Ontology-based Health Information System: A systematic Approach

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Abstract: Ontology as a creative tool plays an essential role in acquisition and organization of knowledge and its representation in a special field. The important point is that ontology is usually applied in designing information systems and is useful for providing healthcare in design of health information systems by providing a comprehensive model of information and process needs. This comprehensive review study is based on existing resources and articles. Considering that a special methodology is used for creation and development of ontology in each domain, therefore, a methodology was presented for designing ontology of health information systems in the conducted studies and based on the general model by Pinto and Martin. The general model was changed in healthcare in order to support design and evaluation of information systems. This systematic approach includes the following three groups; stages, activity, and output. These stages include: specification, conceptualization, formalization, implementation, evaluation and maintenance. It should be noted that two main challenges are observed in designing ontology-based health information systems: designing useful and accurate comprehensive ontologies in healthcare systems, the second challenge is how ontologies should be coordinated with designing and evaluating health systems.Accepting a framework based on ontology provides a strong opportunity for integration and analysis of supervision system data and allows for executing rules based on evaluation in domain of health information systems.
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1. Introduction

Recent advances in the field of information and communication technology have provided new opportunities for executing high-quality healthcare information systems. These technologies improve data processing, more precise diagnosis and easier access to medical services. To this end, an ontology-based approach is necessary in medical world in order to present entities, ideas, events and relations as a form of knowledge representation [1]. Ontology as a creative tool plays an essential role in acquisition and organization of knowledge and its representation in a special field [2] and has penetrated into computer and information science fields in recent years [3]. In this regard, Fonseca also declared that ontology provides services by elaborating on designing information systems or producing and validating components of an information system [4] and can help create common semantic understanding of information and clearly describe the hypotheses [5]. The important point is that ontologies are usually applied in designing information systems [4] and are useful in designing health information systems through providing a comprehensive model of information requirements and a process for providing therapeutic and health care services [2]. In order to overcome problems relating to extraction of information from extensive scientific sources and support decision making, it is necessary to understand methodology of ontologies in healthcare. Therefore, in this study, ontology development was described with a systemic approach in healthcare.

2. Review of Ontology in Healthcare

2.1. Definition of Ontology

Ontology is a basic description of entities in the world. In philosophy, ontology is a branch of metaphysics that deals with being. In computer and information sciences, ontology is often regarded as an artifact engineering in which special words are formed for describing special realities and a set of correct and clear hypotheses regarding meaning of words is formed [4]. Ontology, as a semantic tool, means structured knowledge of a special field which has been formed by providing concepts and relations between them in that field [5]. The computer experts have adopted the term ontology from other sciences, like many other terms of this field, and have given a

technical meaning to it. In computer science, it may be better to refer to definition by Geraber and Studer who called ontology as special conceptualization, explicit and formal sharing of a concept. In this definition;

- Conceptualization means creation of an abstract model from some phenomena in the world in which relations between some concepts and phenomena are identifiable.
- Explicit means that definition of all limitations of use has been explicitly mentioned.
- Formal refers to the fact that ontology should be machine readable.
- Sharing reflects the fact that ontology is consensual knowledge [6].

Chandrasekaran (1999) defined ontology as a content theory about object setting and specifications and relations between objects which may be mentioned in a special field of knowledge [7]. In information technology, ontology has a somewhat different meaning. In summary, it can be said that ontology means formal description of words in a special field. A more accurate definition of ontology in the field of information technology is as follows: Ontology defines words and concepts (used for describing and representing a domain). Ontology is an engineering product including a certain dictionary for describing a part of realities with a set of explicit hypotheses [8]. In biomedicine, ontology is defined as knowledge engineering and shared knowledge repository which extracts new knowledge from the current knowledge and provides a database for collection in a field and sharing and reusing it for the detection of new knowledge [6].

2.2. Types of Ontology

The issue which has attracted a lot of attention in the past years in ontology engineering is specifications of ontology formation process which is called lifecycle and the methodologies which guide how to make ontology. The ontologies can be made from scratch or by reusing the available ontologies. Different types of ontology include:

- Representations: They define knowledge representation system. Ontology of object-based representation systems such as frame of ontology which includes classes, samples, relationship between classes and super classes are defined.
- General or high-level: Definition of very general concepts which can be used in several fields and applications such as simple time ontology which presents some concepts such as time point, interval and relations between two time intervals.
- Domain: This includes definition of available concepts in a domain. Ontology of chemical elements includes concepts in classes of reaction of chemical elements, oxygen of chemical elements and electronic analysis of each chemical element [8].

2.3. Application of Ontology

Ontology has a hierarchical structure of concepts and their relations which is made in order to extract new knowledge. Ontology is related to providing explicit information and knowledge and its main applications in information systems include extracting and collecting knowledge, sharing knowledge and reusing formal knowledge presented between systems, managing terminology, creating terms for knowledge representation, saving, analyzing and retrieving data, demonstrating relationship between concepts, knowledge repository, discovering knowledge, reusing knowledge for decision support systems, integrating and interoperability and accessing conceptual information [6].

2.4. Applications of Ontology in Medicine and Biomedicine

Medicine is a very complex domain for purpose of modeling and semantic representing. This is due to the presence of different specialties (clinical versus executive knowledge), different scientific transparencies (molecule versus organs), different needs of users for presenting services and ambiguous terminologies available in this field [9]. In medical field, application of ontology is a response for reusing a massive and complex volume of information [10]. Yu regarded a function of ontology in biomedical field which included management of terminology, integration and sharing of data, reusing knowledge and supporting decision making [10]. Ceusters et al. believed that ontology in healthcare causes effective support of data retrieval, use of different kinds of formal reasoning and reduction of harmful effects of data repository formation in medical database [11]. Ontology plays an effective role in validation and improvement of software products. It covers the gap between users and developers like a bridge. By using compatibility ontology, authenticity and comprehensibility of models against primary needs of system can be better described. Ontology is regarded as a faster way for easier development and understanding compared with other models of analysis and design because of requiring special and deep methodological knowledge [12].

3. Ontology in Health Information System

In healthcare, use of ontology dates back to 1968 and is related to creation of problem-oriented record system. This approach also entered electronic

health record in 1992 [3]. It has been proved that information systems being or having been designed in healthcare face many challenges. Executive weakness of such projects is due to construction and design of systems based on wrong hypotheses or weaknesses of information about needs of users [2].

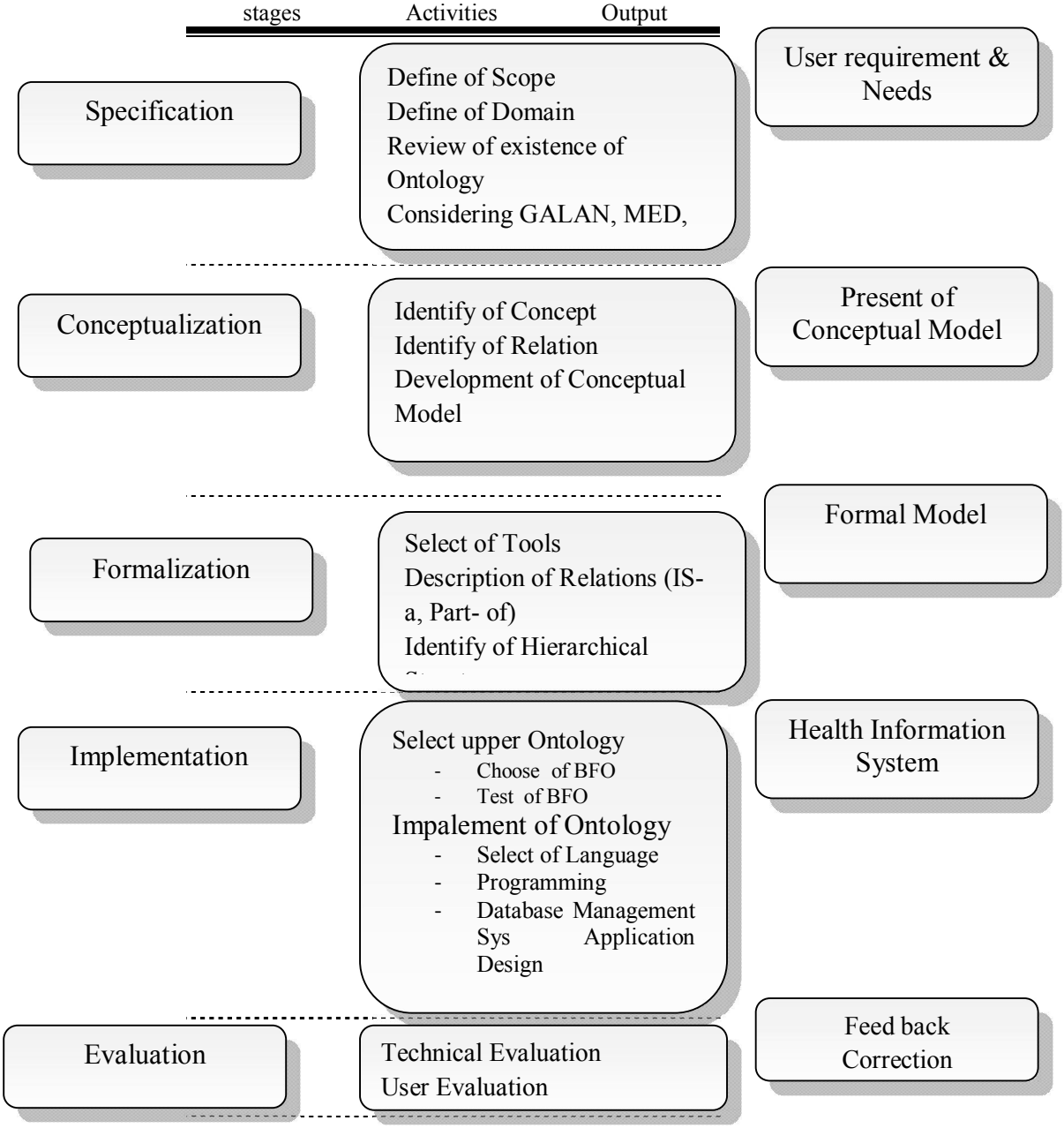

Figure 1- Systemic approach for designing ontology-based information system

The above figure shows five main stages with a systemic approach.

Systems and models which are designed without considering the real world will not have proper performance. For this reason, ontology can lead to "description of reality" and helps describe and formalize processes and information [13]. In fact, ontological analysis provides a structure of knowledge and ontology is regarded as the heart of knowledge representation systems for that domain [7].At present, focus of new information systems has changed from data processing to meaning processing. For this reason, the basis of processing is a semantic concept instead of data in the present systems. This comes with its own special interpretation, and is juxtaposed to other concepts inside a text and is related to them [5]. Today,

ontology is rapidly expanding as a necessity in proper design of information technology tools, especially database because ontology allows organizations to store data based on logical and defined laws which are comprehensible for both humans and machines. This causes reuse and interoperability of information in databases and related sources [14].

4. Presentation of Methodology for Designing Health Information Systems

Ontologies are important in most fields such as knowledge management and knowledge organization, e-commerce and extraction of information. Different methodologies have been raised for making ontology [15]. Considering that a special methodology is used for creation and development of ontology in each domain, therefore, a methodology was presented for designing ontology of health information systems in the conducted studies and based on the general model by Pinto and Martin. The general model was changed in healthcare in order to support design and evaluation of information systems. This approach includes the following five stages: specification, conceptualization, formalization, implementation, evaluation and maintenance.

Stage 1: Specification

In this stage, the goal and scope of ontology are specified and also the ontologies available in ontology repository such as NCBO Bioportal, Protégé wiki and Open biomedical Ontology foundry are studied in order to provide a comprehensive coverage and acquire the required knowledge. The standards of GALAN, MED and SNOMED CTs are also included. In this stage, these questions are answered: Why is ontology made? Who are end users and what do they intend to do?

Stage 2: Conceptualization

In this stage, concepts, words and communications required for designing ontology are identified. Then, a conceptual model of ontology is described. Of course, different methodologies use conceptual models differently. Conceptual models in ontology include concepts of domain and relationship between concepts. The relationship between concepts creates some groups of concepts and these groups form different modules (subontology) inside that domain.

Stage 3: Formalization

After designing a conceptual model, ontology domain is created and developed in a formal model of concepts and groups. Formalization is completed by developing a hierarchy and identifying communications such as Part-of and IS-a. Formalization is done in three cases: ontology, subontology and problem solving approaches. Domain and subontology represent the structure and communication of ontology and problem-solving approaches provide special solutions for problems. At the end, all stages are revised in terms of clarity, coherence, extendibility and redundancy reduction.

Stage 4: Implementation

In this stage, health information system is implemented. This stage includes two stages of upper ontology and ontology. In the first stage, Basic Formal Ontology (BFO) is tested in terms of integration and generality in the field of health information system after selecting BFO. In the second stage, language is selected based on automated reasoning, consistency checking, facility reasoning and semantic rule. Then, designing structure, programming, database management system and application design are conducted. These stages will be useful when a prototype is rapidly created and tested and necessary feedbacks are given to the system design process.

Stage 5: Evaluation and Maintenance

There are different methods for evaluating ontology. These include user evaluation and technical evaluation. Technical evaluation is related to constructed ontology. User evaluation assesses applications, methods and concepts of ontology domain.

5. Related Works and Conclusion

Different methodologies have been introduced for constructing ontology. One of these methodologies is for Ushold and King which includes four components; goal identification, ontology construction, evaluation and documentation. This methodology is the result of enterprise ontology (EO) and is general and can be applied in other fields. The basis of this methodology is development of informal ontology and its stages are explained below:

1- Defining the domain
A- Collecting concepts through brain storming
B- Classifying the collected concepts
C- Revising the set of concepts with researches for studying main concepts and proportion of general and special concepts
2- Identifying terms

For each concept, a term with one meaning is selected and even if there is not a suitable term for a concept, a new term is created.

3- Definition

Definition of meaning in ontology is very sensitive and a single meaning should be presented by developers for each concept [15-17].

Another methodology is called as TOVE, this methodology was created and expanded for assisting model organizational process in University of Toronto. This methodology is composed of the following main stages:

1- Creating an informal scenario for formalizing special needs of ontology
2- Using scenario and formulation of suitable questions for responding to the created model based on ontology. For example, the following suitable questions can be used:
   - What activities are performed for reaching the goals?
   - What specifications and sources do the future activities have?
1- Extracting a set of terms out of the questions and then formulating terms to a formal and contractual language in ontology
2- Formalizing suitable questions by defining terms and determining axes for their interpretation
3- Creating conditions for describing comprehensive ontology [15-17]

Methodology was developed in Polytechnic University of Madrid based on standards of IEEE for the lifecycle of software development. Some of the stages include:

1- Project management process

Some instructions for planning, project control, quality control

2- Ontology development process

Some instructions for using ontology, explaining vision of users, conceptualizing the desired domain, formalizing ontology and execution

3- Supporting activities

Some instructions for acquiring knowledge, evaluating and integrating ontology, documenting and managing versions [15-17].

On-To-Knowledge methodology was created and developed in university of Karlsruhe based on two-loop architecture, knowledge process and knowledge meta-process for introducing and protecting ontology-based knowledge management.

Knowledge process is use of ordinary knowledge and evaluation of processes but knowledge meta-process is the methodology of ontology development which is comprised of five main steps:

1- Feasibility study
2- Kickoff
3- Refinement
4- Evaluation
5- Application and evaluation [15-17]

Activity – First Method (AFM), It is a method which creates ontology of tasks and fieldwork by using technical documents. One of the main ideas in this method is that task ontology makes user face to a set of roles in work field and concepts should be identified based on roles and tasks ontology. This method has four stages and 12 steps as shown below:

Stage 1: Extracting task-units

1- Division of text to smaller blocks and extraction of terms
2- Extraction of task-units such that one process is extracted from each block
3- Preparing a flowchart by combining tasks of units which is called concrete task-flow

Stage 2: Organizing task-activities

4- Conceptualization of activities relating to tasks based on actions in unit tasks
5- Organization of work activities in a hierarchy
6- Definition of role –concept which is called task-activities and explains input and output in work activities

Stage 3: Analyzing task-structure

7- Generalizing main task flow for obtaining general workflow
8- Describing object flow which explicitly describes the relationship between input and output of work activities in the above workflow
9- Definition of work role which have been performed based on the object flow
10- Extraction of domain terms which play a role in work field

Stage 4: Organizing concepts of domain

11- Distinction between main concepts and concept-based roles
12- Organization of concepts in hierarchy of IS-a [15-17]

In the paper which was presented by Craig E. Kuziemsky and Francis Lau (2010), for designing health information systems, general model methodology presented by Pinto and Martin was suggested which considered ontology development to include the following four stages:

- Specification and conceptualization
- Formalization
- Implementation
- Evaluation and maintenance [2]

Here, it should be noted that two main challenges are observed in designing ontology-based health information systems:

A- How should comprehensive ontologies be designed useful and accurate? Because decision making is very complex in healthcare systems and there is urgent need for integration.
B- The second challenge is how should ontologies be coordinated with designing and evaluating health systems? In fact, it should be specified how ontologies are developed in the field of

healthcare and then how they are used for designing and evaluating health information systems [2].

Today, intelligent systems are made based on ontology to operationalize the model and its different components. Accepting a framework based on ontology provides a strong opportunity for integration and analysis of supervision system data and allows for executing rules based on evaluation in domain of health information systems.

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References

1. Cenan C, Sebestyen G, Saplacan G, Radulescu D, editors. Ontology-based distributed health record management system. Intelligent Computer Communication and Processing, 4th International Conference; 2008 28-30 Aug; cluj-Napoca, Romania.
2. Kuziemsky, C.E. and F. Lau, A four stage approach for ontology-based health information system design. Artificial Intelligence in Medicine2010; 50(3): 133-148.
3. Safdari R ,Partovipour E , Maidani Z. Unified Medical Languge the infrastructors of EHR. Tehran: jafari press;2009.
4. Fonseca, F. The double role of ontologies in information science research. Journal of the American Society for Information Science and Technology 2007; 58(6): 786-793.
5. Dastgerdi F A. Ontology Evaluation: Consideration of Criteria, Approaches and Layers. Journal of Information processing and Management 2012; 27(2): 533-559.
6. Verma A.Ontology Based Personalized Modeling forChronic Disease Risk Evaluation and nowledge Discovery: An Integrated Approach[thesis]. New Zealand: Auckland University of Technology; 2009.
7. Chandrasekaran B, Josephson J.R, Benjamins V.R. What are ontologies, and why do we need them? Intelligent Systems and Their Applications, IEEE 1999; 14(1): 20-26 .
8. Shadgar B, Asareh A, Haratiyannejad A. Semantic Web- Concepts and Techniqe. Tehran:Armaghan Press; 2010.
9. Eccher, C, Purina B, Pisanelli D M, Battaglia M,Apolloni I, Forti S. Ontologies supporting continuity of care: The case of heart failure. Computers in biology and medicine 2006; 36(7-8):789-801.
10. Yu A.C. Methods in biomedical ontology. Journal of biomedical informatics 2006; 39(3): 252-266 .
11. Ceusters W, Smith B. Foundations for a realist ontology of mental disease. Journal of biomedical semantics 2010; 1(1): 10.
12. Lopez-Lorca A, Beydoun G , Sterling L, Mille T. An Ontology-Mediated Validation Process of Software Models 2010.[Epub] Available from: http://ww2.cs.mu.oz.au/~tmill/pubs/isd2010. pdf.
13. Beale T, Heard S. An ontology-based model of clinical information. Studies in health technology and informatics 2007;129(1):760.
14. Topalis P, Mitraka E, Bujila I, Deligianni E, Dialynas E, Siden-Kiamos I,et al. IDOMAL: an ontology for malaria. Malaria journal 2010; 9(1): 230.
15. Pinto H S, Martins J P. Ontologies: How can they be built? Knowledge and Information Systems 2004; 6(4): 441-464.
16. Ushold M, King M. Towards a Methodology for Building Ontologies. In Proc. of the Workshop on Basic Ontological Issues in Knowledge Sharing (IJCAI95 workshop). 1995 [Epub]. Available from: ftp://ftp.aiai.ed.ac.uk/pub/documents/1995/95-ont-ijcai95-ont-method.ps. gz
17. Iqbal A M. An Ontology-Based Electronic Medical Record for Chronic Disease Management [thesis]. Halifax, Nova Scotia: Dalhousie University; 2011.

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