An Ontology Approach for Knowledge Acquisition and Development of Health Information System (HIS)

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Abstract

This paper emphasizes various knowledge acquisition approaches in terms of tacit and explicit knowledge management that can be helpful to capture, codify and communicate within medical unit. The semantic-based knowledge management system (SKMS) supports knowledge acquisition and incorporates various approaches to provide systematic practical platform to knowledge practitioners and to identify various roles of healthcare professionals, tasks that can be performed according to personnel's competencies, and activities that are carried out as a part of tasks to achieve defined goals of clinical process. This research outcome gives new vision to IT practitioners to manage the tacit and implicit knowledge in XML format which can be taken as foundation for the development of information systems (IS) so that domain end-users can receive timely healthcare related services according to their demands and needs.

Keywords: Knowledge management, Health Information System, conceptual modelling, information logistic, EKD, OWL, ward-round.

1. Introduction

In order to realize the importance of knowledge management (KM) in various domains especially healthcare industry, many organizations are striving to manage numerous format of knowledge. The importance of variety of knowledge such as common sense, meta information, heuristic, domain knowledge, tacit knowledge and explicit knowledge [1] enforce healthcare organizations to re-structure their infrastructure to manage diverse knowledge and human capital. KM also emphasizes to fulfil organization's needs in improvement by managing knowledge at strategic, managerial and operational levels and gives holistic, comprehensive platform to facilitate healthcare end-users according to their needs and demands [2]. The emergence of information and communicational technologies (ICT) and modelling techniques work as enabler to acquire and manage tacit knowledge from domain experts, and to transform into machine readable format. Current health information system (HIS) do not fulfil the needs of the healthcare professionals and unable to facilitate patient preferences due to organizational and technical limitations in healthcare sector. To achieve better usage of HIS, there is a need of formal method or technique which helps to understand healthcare processes, which are to be supported by HIS, the needs of the people who are going to use HIS, and detail information of healthcare domain [3].

Various healthcare organizations are facing several challenges to address tacit knowledge acquisition issues. Firstly, *how to deal and extract tacit knowledge which is in the minds of domain experts for optimized internal communication among various individuals and for the information flow within healthcare organization* and secondly, *how to transform the tacit knowledge into machine readable form to build the semantic-based knowledge management System (SKMS) which further leads to the implementation of healthcare information system (HIS) and its services.* The advantage of this (SKMS) is to deliver timely information according to the healthcare professional's demands and patient's care needs in healthcare units [2]. The HIS supports many characteristics such as, to incorporate systematic leverage of data, information, skills, expertise and various form of assets and capital to improve organizational innovations, responsiveness, productivity and competence of the individual in the organizations [2].

For tacit knowledge representation, various modelling techniques such as business process model and notation (BPMN) [4], unified modelling (UM), IDEF modelling approach [5] and methods [6] have been proposed in healthcare sector for constructing models which depict tacit knowledge and serve to provide the right information to the right user at the right time in different contexts in healthcare unit [7]. Although, Enterprise modelling (EM) technique has been used favorably for supporting a set of structured, goal/problem-driven models for capturing, representing and structuring organizational tacit knowledge [3]. EM technique is also used to incorporate different perspectives of healthcare process modelling with respect to functional, informational, organizational and behavioral [8].

The main contribution of this paper is to propose a formal method (ontology-based approach) to address tacit knowledge acquisition issues and information flow problems. The practical framework for semantic-based knowledge management system (SKMS) is quite useful to contribute for providing the right information to right end-users according to their demands in different tasks to perform different activities in ward-round process of healthcare unit [9]. This formal method can be used to transform tacit knowledge acquisition to (SKMS) which is in machine readable form to enhance the performance of the health information system (HIS) for efficient information retrieval against healthcare professional's queries in various healthcare units.

This paper is structured as follows. Section-2 briefly explains the importance of knowledge management (KM), describes knowledge management issues, reusability of existing ontologies. Section-3 illustrates the Ward-round (WR) process and presents the case study. The methodology which is used for carrying out this work is presented in section-4 and different knowledge acquisition approaches in details which supports to develop a practical framework for semantic-based knowledge management system (SKMS). Section-5 discusses about the experiments, results and their evaluation. Section-6 explains implication and limitation of the study and the conclusion of the work is presented in section-7.

2. Literature Review and Conceptual Basis

2.1. Knowledge Management (KM)

The concept of KM in healthcare organizations [10] is to focus on some critical issues related to knowledge acquiring from numerous domain experts as tacit knowledge and to improve the information flow problems in healthcare processes. The term KM is categorized into two major discipline; explicit knowledge (EK) and tacit or implicit Knowledge (TK) [11]. The concept of tacit knowledge is linked to personal perspectives, it is intangible and not easy to articulate. Similarly, the explicit knowledge has tangible dimensions that can be easily captured, codified and communicated [12]. A perquisite requirement for the implementation of (SKBS) is to understand and develop the structure of domain elements as taxonomy which supports knowledge acquisition process and its management, transfer of tacit knowledge into explicit knowledge [13].

Knowledge acquisition is the way which deals with acquiring and extracting the knowledge from knowledge-based resources [14]. These resources can be considered as human capital or any other database repositories, in collaborative healthcare environment, the first step of KM is acquisition of the knowledge, this level involves in various sequential steps that are very important for knowledge acquisition process from the right people, at right time and right place [15]. It is very difficult to evaluate various knowledge acquisition techniques which have been introduced due to the costs of extracting knowledge embedded inside domain experts minds [16]. Usually, knowledge engineers faced some serious challenges related to knowledge acquisition process during building a knowledge-based system, so they must realize, how to acquire and capture the knowledge from various information channels and how to execute in a systematic way with optimal cost factors within healthcare organization [2].

2.2. Knowledge Management and the Reusability of Existing Ontologies in Healthcare

Knowledge management issues vary from business to business, when talking about in healthcare organizations, these critical issues are; *firstly*, how to extract and acquire the tacit knowledge from domain's experts and knowledge-mentors especially in specific healthcare unit. Here, the tacit knowledge is considered as observational, experienced-based knowledge, so this means that if you want to extract this typical knowledge you need a method or technique to contact expert's mind and extract its knowledge easily [2]. *Secondly*, experts have large amount of observational and experience-based knowledge. Although, several methods can be utilized for the extraction of these types of knowledge such as printed documents, interview and reported while others are very difficult. *Thirdly*, experts are not available all the time and do not want to waste their time in interview or documentation. *Fourthly*, they are unaware, how to transform the tacit knowledge into machine readable-form to build intelligent Semantic Knowledge-based System (SKBS) for getting the right information at right time, right context and right location.

Nowadays, for the transformation of tacit knowledge into machine readable-form, various following approaches are used to facilitate domain-knowledge in the form of information model explicitly in healthcare sector. The archetype pattern approach is employed to develop an ontology or conceptual modelling for a health information system (HIS) and considered as foundation for providing shared understanding of healthcare processes in healthcare unit [17]. The ontology-driven multi-agent approach provides a framework which is used to help the medical professionals to interact and collaborate efficiently for effective decision-making in patient treatment processes [18]. The competence management approach is also used to develop goal-oriented shaping and development of individual competencies based on defined goals at enterprise level [19].

According to [20], various approaches are utilized to model ontologies in healthcare domain to produce controlled lexicons for regulating schemes in medical informatics and its usage in healthcare sector. Various existing ontologies; *EcoCyc* [21], *TABIS* (Transparent Access to Multiple Bioinformatics Information Resources) [22], SNOMED CT, RxNorm, MeSH, ICD-10, Gene Ontology [23]. For the conceptual modelling development is concerned, numbers of methodologies have been proposed such as Methontology [24,25], Tove, KBSI IDEF5 (knowledge-based systems, Inc.) [26], Model-driven Ontology [27], On-To-Knowledge Methodology (OTKM) [28]. Here, modelling techniques can be considered as one of the mechanisms for sharing domain knowledge among domain users and healthcare practitioners. we tried to connect these knowledge acquisition issues with case study at Ryhov hospital, Jönköping, Sweden for better understanding.

3. Research Method

3.1. Case Study

The aim of this case study is to improve healthcare processes (Ward-round) and this work is partly carried out with in the project "Bridging the Gaps" which was driven by The Jönköping Academy[1] for the improvement of health and welfare. In ward-round process, multidisciplinary healthcare professionals with various competencies, skills and assigned distinct roles gathered at the designated time to assess the patient's status, collect information for making diagnosis as well as making plan for the patient's treatment process. Multidiscipline healthcare professional can be categorized into; consultant, senior practitioner, junior practitioner, head nurse, additional nurse, psychiatrist and laboratory personal. The head nurse consults the *EBBA* (patient-admittance status system) information system to get data about availability of vacant beds to enhance the treatment pace of normal patients, emergency patient, patient sent from other healthcare units and patient admitted through the certain ward. EBBA is Swedish patient-admittance status system. Every morning, the medical staff receives information regarding a patient in the form of medical reports from various information channels e.g. *Cambio Cosmic* (electronic medical record system), it is patient record keeping system. These medical systems such as EBBA and medical databases are also connected with unit pathology laboratory system. These systems work in collaboration to disseminate the information which further leads to support intelligent decision-making process in real-time scenario during ward-round in healthcare unit. Although, still, it is difficult, how to extract most relative information from resources and perceive the information from the multidisciplinary personal and to improve the information flow with in the ward-round process for quality patient treatment in Ryhov hospital[2], Jönköping, Sweden. The further detail about case can be bound in [7].

3.2. The Ward-round (WR) Process

The ward round (WR) process [29,30,31] is a group of activities which maintains various healthcare professionals with multidisciplinary backgrounds, skills, and competences to execute various tasks according to their expertise for the patient's treatment. Commonly, we can divide the ward-round into three sub-processes *1)* pre-ward round (PRW), *2)* ward-round (WR) and *3)* post ward-round (PWR). The PRW process describes about prerequisite events and defined tasks before conducting the ward-round process and PWR process invites the junior practitioners and medical students to suggest and evaluate the current patient's illness status. It also provides a platform for juniors and medical student to propose optimal solutions with convincing arguments for the quality patients' treatment and learning perspective [7]. The PRW process and PWR process which consequently support each other [3]. The ward-round supports patient treatment planning, prognosis formulation and analysis of social, psychological, rehabilitation and placement issues [30]. The ward-round process constitutes of different tasks, roles, set goals and certain activities which can be shown in figure-1, where multidisciplinary healthcare professionals with assigned distinct roles in the WR process perform certain activities to fulfil certain tasks and achieve certain ward-round related goals by using various tangible and non-tangible resources for quality patient's care.

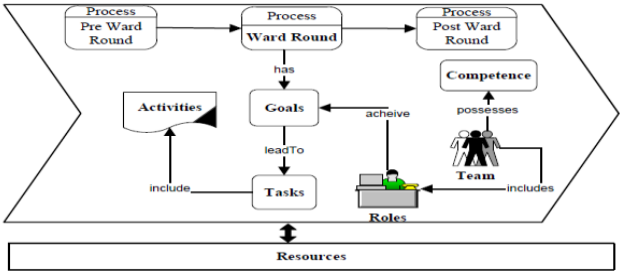

Figure 1. Conceptual Model of Ward-round Process

3.3. Data Collection

For data collection, we conducted two modelling workshops with domain experts and knowledge mentors and one personal interview with the head nurse at Ryhov, hospital, Jönköping, Sweden. We collected the primary data by using modelling workshop technique from the multidisciplinary personnel (see table 1). For the improvement of information acquiring process, we developed the case study which can be seen in detail in theoretical section.

Primary Data Sources	Description
Workshop I	Primary data was collected from multidisciplinary personnel such as medical nurse, medical practitioners etc. • Receive the data related to the ward round resources such as EBBA (patient-admittance status system), Cambio Cosmic (electronic medical record system), laboratory database. • Different multidisciplinary participants with various competences and skills are gathered at designated time 9:00 A.M every day and received the patient's routine status manually. • The routine patient's medical history is evaluated through observations in day and night patient's treatment and laboratory report's status while monitoring session at 7:30 A.M every day. • The senior and junior practitioners used to discuss patient's status at 9:00 A.M every day • Consultant and senior practitioners used to visit the patient for Ward-round in designated days (Monday, Wednesday, Friday) of the week and rest of other days (Tuesday, Thursday) other staff members like junior practitioners, nurses, assistant nurses and occupational therapist are involved to analyze patient's treatment.
Workshop II	• To develop the process view of ward-round by using EKD modelling technique • Assigned distinct roles to medical professionals with various competencies to initiate different processes and perform various activities to achieve ward-round defined set goals. • Develop conceptual model in ontology-based editor tools like Protégé 4.1[3] and Top-braid composer[4].
Personal Interview	One interview with head Nurse is conducted to know some responsibilities before going into the ward-round processes in Ryhov hospital, Jönköping, Sweden. • The head nurse is used to inform acute clinic examination team at designated time 11:00 A.M every day for patient's admission in healthcare unit according to the patient's serious conditions. • Receive the patient report from different information channels like EBBA, Cambio Cosmic and laboratory database

Table 1. Data Sources

3.4. Data Analysis

The data analysis section can be described as a four phase processes: knowledge elicitation, tacit knowledge modelling, conceptual modelling, deployment and evaluation (see table 2). First, we used tacit knowledge acquisition approach as modelling workshop and elicited knowledge from domain experts, medical and IT practitioners in workshop I, II. Using our conceptual modelling basis, we perceived some key concepts related to ward-round and identified various key actors and their assigned distinct roles, various tasks and their activities and defined set goals. The second phase of our data analysis explains about, how knowledge

modeler perceives the knowledge from various sources and model them by using modelling techniques e.g. EKD in modelling tools e.g. MS Visio[5] and Cmap[6]. The third phase of our data analysis is, how ontology modeler transforms the process view of ward-round into the conceptual model and construct ward-round ontology (knowledge-base) using OWL[7] in ontology editors such as protégé 4.1 and Top-braid composer. The fourth phase of our data analysis explains the mechanism of transformation from tacit knowledge to explicit knowledge using Jena APIs[6] and constructs machine readable format in the form of RDF/XML[10] or OWL/XML[11]. This phase also emphases on different evaluation strategies to verify the conceptual-model and justify competence questions which help to confirm that the conceptual or ontological-model contains enough information to answer these questions which are related to the domain (the ward-round).

Steps	Tasks	Outputs
Knowledge Elicitation	• Elicited knowledge from workshop I, II. • Construct competence questions • Decide knowledge modelling techniques e.g. EKD.	• Research data repository • Identify numerous key concepts related to the ward-round processes. • Identify distinct roles, various tasks and their activities, different ward-round goals. • Mentioned different conceptual modelling tools like M.S Visio. • Select Jena APIs for the development of ward round process.
Tacit Knowledge Modelling	• Knowledge modeler perceive the tacit knowledge from different sources and model them.	• Process view of the ward round. • Information sets • External process • Key processes
Conceptual Modelling	• Ontology modeler transform process view of ward round into conceptual model. • Construction of ontology using OWL	• Conceptual model. • Definition of axioms • Representation of tacit knowledge ontology editor tools like protégé.
Deployment & Evaluation	• Transformation of tacit knowledge into machine readable form. • Code generation using Jena APIs. • Evaluation using DL Query, Manual Assessment	• Construct OWL/XML and RDF/XML structure • Health services delivery in ward-round. • Execution results to justify competence questions.

Table 2. Data Analysis

4. Methodology

4.1. Building an Approach for Tacit Knowledge Acquisition

Numerous modelling techniques have been suggested for the tacit knowledge acquisition and address aforementioned issues [4], [5], [6] but enterprise knowledge development (EKD) modelling technique [8] is considered the most promising especially in modelling workshop [3] for healthcare study.

The Modelling Workshop: The modelling workshop is the platform where multidisciplinary personnel with their expertise, experiences and competencies can share the information and tacit knowledge from their previous experiences. The EKD helps to acquire the tacit knowledge from the domain experts according to their skills, experiences and competence during the modelling session for the systematic work-flow in healthcare processes.

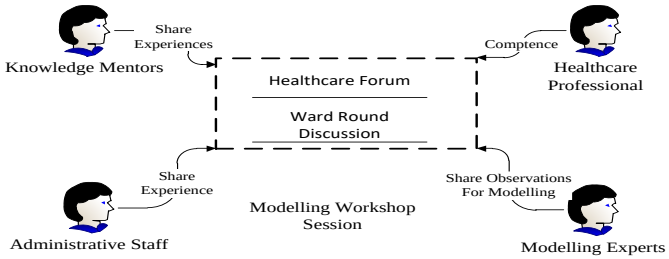

Figure 2. The Modelling Workshop

The modelling workshop which is mentioned in figure-2, followed certain activities which help to acquire tacit knowledge from the knowledge mentors, domain experts related to the ward round. Certain set of activities are designed as: arrange a modelling workshop with knowledge mentors, domain and modelling experts, acquire tacit knowledge (observations, experiences) about the ward-round process while conversation from domain experts or healthcare personal, prepare the case data based on the modelling workshop according to aforementioned case study, support the case with the study of related literature, analyse the results of the domain modelling and literature review, determine appropriate tasks, processes, activities and roles comprising the ward round, describes steps needed to perform tasks, select a suitable methodology for implementation of the model as formal ontology and perform the implementation, verify and evaluate the constructed model through domain expert's assessment [3].

4.2. Building an Approach for Explicit Knowledge Acquisition

Due to new business demands, the importance of enterprise modelling (EM) technique is increasing day by day in multinational organizations due to its effectiveness, so conceptual modelling is one of the techniques of EM [33]. In this section, we chose hybrid method technique [7] that is highly customized from Methontology [34] and Toronto Virtual Enterprise (Tove) [26] for the construction of the domain ontology. The main objective of hybrid method is to build ward-round process using semantic web editors such as protégé, top-braid composer. This ontology development is inspired from the software engineering paradigm and follows all necessary phases which are involved in process orientation in software development life cycle (SDLC). The hybrid method is constituted of different activities which are explained in figure 3. These activities can be categorized into development activities, supportive activities and management activities [7].

4.3. Building an Approach for Explicit Knowledge Acquisition

In the section, the proposed framework is based on N-layers architecture which can be seen in figure 4. This N-layers architecture performs numerous functionalities which are discussed in the following section.

First Layer is reserved for acquiring tacit knowledge by using modelling workshop technique from the domain experts where knowledge modeler develops the model by using modelling technique e.g. EKD and tools e.g. M.S Visio in modelling session which is explained in knowledge acquisition approaches section in detail 4.1.1 section.

Second Layer is reserved for data access from various health information systems and data repository for data synchronization in conceptual modelling development process.

Third Layer explains the role of the ontology developer who perceives the information from EKD model and develops into the conceptual model (ontological model) with integration of existing health ontologies for specific healthcare processes in semantic web editors e.g. protégé 4.13 and Top-braid Composer[4].

Fourth Layer is reserved to explain ontological-based domain model implementation in ontology web language (OWL)[5] with Jena APIs[6].

Domain Ontology Management with OWL Syntax: In logical layer, OWL is designed to apply not only for the presentation of the domain knowledge but also processing the content of information in medical unit [35]. The figure 4 illustrates a brief practical N-layers (SKMS) framework which is based on OWL-based conceptual modelling for supporting healthcare process, activities and different patient-oriented services in healthcare unit. These layers perform distinct functionalities to achieve healthcare related services according to the multidisciplinary professionals needs and their demands in specific healthcare unit. This N-layers based semantic knowledge management system also supports various OWL supported axioms and their properties for better understanding of descriptive knowledge. To exploit the expressiveness of the domain knowledge, we specified some axioms that work directly with the class objects to improve the expressivity of the domain knowledge (ward-round) in the construction of domain ontology model. These axioms are categories into transitive, reflexive, irreflexive, symmetry, asymmetry and inverse axioms in the ontological modelling development [36]. The OWL axioms and their properties can be helpful to restrict classes which are involved in healthcare process (ward-round) and support to enhance the expressivity of RDF-triples[9] in ontological model for intelligent behavior in health information system (HIS).

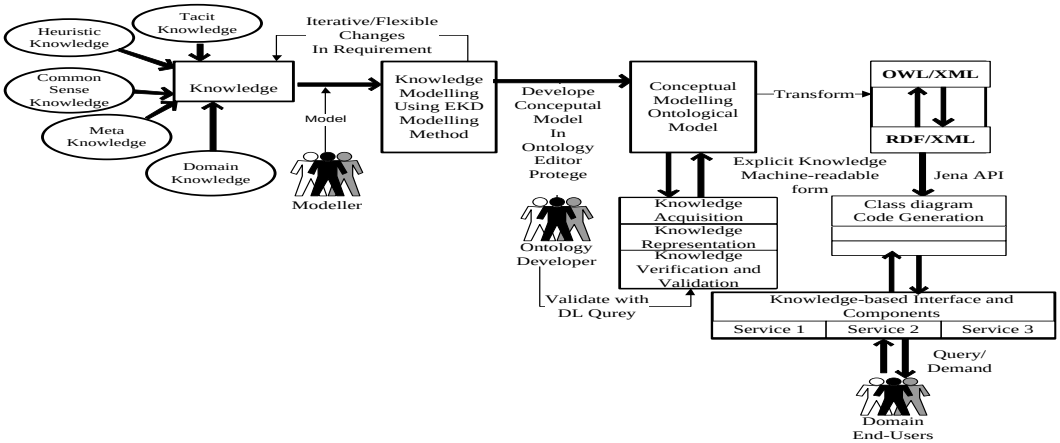

Figure 3. N-Layers Semantic-based Knowledge Management System (SKMS) Framework

5. Results

The conceptual modelling or ontological model is considered one of the techniques to model the domain knowledge in formal way. According to the [37] "*an ontology is an explicit*

specification of a share conceptualization of a domain which is machine readable and human understandable". Ontology can be viewed as a shared conceptualization of a domain that is commonly agreed by all parties [39]. The ontology can also be taken into various levels according to its generality, in terms of top-level ontology, domain ontology, task-oriented ontology and application-based ontology [38]. The ontological modelling supports some features of knowledge coverage in terms of domain knowledge and its expressive power and application dependencies efficiently [39]. The ontological modelling helps to acquire the information from the domain experts as tacit knowledge and transform into machine-readable form as explicit knowledge, which results to develop more interesting intelligent, efficient HIS for the improvement of health services delivery in the ward- round process [40]. This proposed ontological model is composed of different class concepts related to the ward-round in hospital unit. This ontological model is true depiction of patient treatment process in ward-round which is focused on things such as tasks, processes, activities, roles, goals and resources [7].

5.1. Transformation Mechanism (Tacit Knowledge to Explicit Knowledge)

In this section, we presented the transformation mechanism of tacit knowledge related to ward-round situation into the explicit knowledge through suggested OWL–based ward-round model. First, we need a domain ontology (ward-round) which describes about various tasks in ward-round e.g. *Patient Treatment Planning Process*, various activities which are performed to initiate the ward-round processes. The constructed ontology contains 146 classes or concepts, 76 object properties, 1 data property and 122 individuals. This ward-round ontology supports to multidisciplinary professional's roles with different competencies to achieve pre-defined set goals by using various resources for the sake of patient-centered quality treatment in ward-round process in Ryhov hospital[2], Jönköping, Sweden.

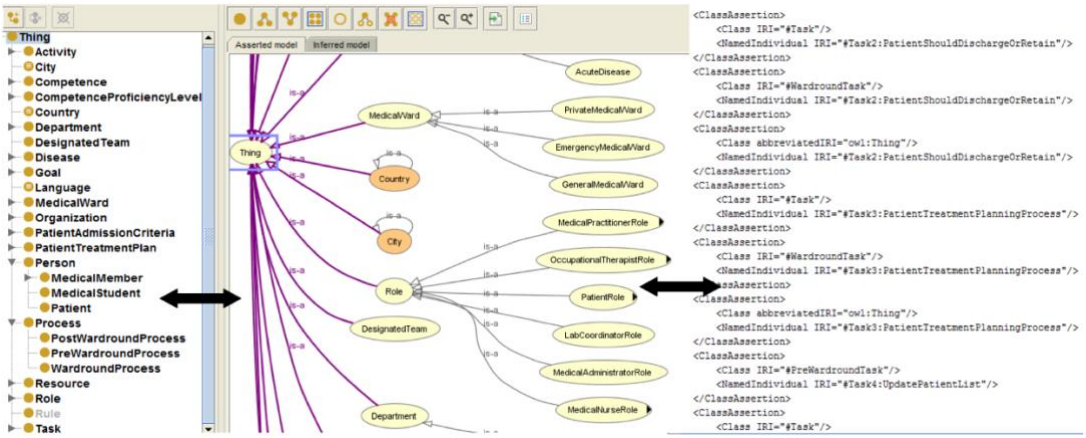

Figure 4. A Ward-round Ontological Model Using (OWL) (Transformation Mechanism)

For the ontology development is concerned, we designed it with semantic web editor e.g. protégé 4.1 which is one of the promising tools to develop OWL-based domain ontology. The figure-5 explains noteworthy features, firstly, gives holistic view of a ward-round ontological model using OWL. Secondly, gives interpretation of XML format which is considered as machine-readable form and thirdly, provides detail information about various classes or domain concepts which are used in ontological modelling such as process classes includes various sub-process classes such as PreWard-round Process (PRW) and Ward-round Process (WP), PostWard-round Process (PWR). These ward-round process classes contain several individuals and properties that are needed when a high-level context of ward-round is composed with RDF-based context in ontology construction (Cho et al. 2011). The main contribution of this ontological model in SKMS framework is to provide the mechanism for the transformation of tacit knowledge into explicit knowledge. It also facilitates health consumers and practitioners. This proposed model also helps to improve information flow in

healthcare processes for optimal information retrieval according to the needs and demands of end-users for quality patient-centered treatment and services in medical unit.

5.2. Evaluation Using Description Logic (DL) Query Tab

In this paper, we evaluated the ontological model which actually gives the holistic view of transformation of tacit knowledge into machine readable format that will be useful for the development of health information system (HIS). Although, we utilized various strategies to evaluate the ontological model to get desirable results in ward-round process in Ryhov hospital, Jönköping, Sweden. We have also used the DL Query Tab in Protégé 4.0 to verify some competence questions. These competence questions help to confirm that the ontology has enough information to answer these questions which are related to the domain knowledge (ward-round) [3]. The mathematical expression of informal competence question is expressed as:

Competence Question: *which roles visit the medical ward daily or oftenly?*
The formulation of informal expression of above mentioned competence question is;

let if *x* belongs to any entity (Role) and *y* belongs to any entity (Medical Ward) that is responsible for visiting the medical ward in defined time in a day.

Role(x); MedicalWard(y); Description(z) <=> CardiologyGeneralWard
Role(x)| MedicalWard(y)=> visitWardDaily(x|y, z)

The above competence question describes the tacit knowledge which usually domain personnel acquire from the system. The DL-Query[7] structure is based on SQL[8] (Structure Query Language) which helps to end-users to access the data in the form of results from the knowledge repository in OWL5 file and figure-6 presents the results of executing the DL-Query in the protégé editor.

Figure 5. The Result of Executing the DL Query Tab in Protégé Editor

6. Conclusion

The objective of this study is to give awareness of various knowledge acquisition approaches in knowledge management in specific domain e.g. healthcare and emphasizes of health information system (HIS) which could be architected to enhance the quality of medical care. With the help of semantic technologies, this paper presents semantic knowledge-based system (SKBS) framework which helps to develop HIS that supports clinical processes like ward-round in health care sector. This framework also supports various knowledge acquisition management approaches (Tacit and Explicit) and gives systematic way, how we can acquire tacit knowledge from the domain experts or knowledge mentors, model it in formal way and transform into the machine-readable form for developing HIS providing various healthcare services that can better fulfil the needs of healthcare professionals and users. The ontological-based modelling approach is the method which invites the organization to move towards patient-centred systems, further opportunities and helps to reuse existing healthcare practices for new reform initiatives. The formal method (ontological-based modelling approach) also gives new vision to manage the tacit knowledge and explicit knowledge and provides help to

develop HIS with mature implementation strategies so that healthcare practitioners can receive healthcare services timely according to their demands and needs in various domains of healthcare sector e.g. ward-round process.

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