

# Design and Implementation of an Ontology-Based Clinical Reminder System to Support Chronic Disease Healthcare

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**SUMMARY** Improving quality of healthcare for people with chronic conditions requires informed and knowledgeable healthcare providers and patients. Decision support and clinical information system are two of the main components to support improving chronic care. In this paper, we describe an ontology-based information and knowledge management framework that is important for chronic disease care management. Ontology-based knowledge acquisition and modeling based on knowledge engineering approach provides an effective mechanism in capturing expert opinion in form of clinical practice guidelines. The framework focuses on building of healthcare ontology and clinical reminder system that link clinical guideline knowledge with patient registries to support evidenced-based healthcare. We describe implementation and approaches in integrating clinical reminder services to existing healthcare provider environment by focusing on augmenting decision making and improving quality of patient care services.

**key words:** *ontology-based knowledge management, knowledge-based decision support, clinical information system*

## 1. Introduction

Chronic illness is typically defined as condition that requires ongoing activities from both the patient and care givers in its treatment. Chronic conditions, such as diabetes, heart diseases, hypertension, etc. are major public health problems in developing countries, as well as in developed countries. As reported in 2004, it was suggested that approximately 45 percents of the US population have chronic illness [1]. While current healthcare systems are designed primarily to treat acute conditions, specific focus is increasingly applied to people with chronic conditions. Treatments of chronic conditions normally require planning and management to maintain the patients' health status and functioning.

The Chronic Care Model (CCM) [2] is a guide towards improving quality of healthcare for people with chronic conditions. The model aims at producing more informed and knowledgeable patients and healthcare providers that can result in higher quality of chronic care. Decision support and clinical information system are two of the main components for improving chronic care. These components must rely on relevant and reliable information and knowledge in order

to assist healthcare providers to deliver higher-quality care service.

Healthcare processes heavily depend on both information and knowledge [3]. Information systems are typically integrated into hospitals to support organization processes such patient record entry and management, result reporting, etc. Although medical databases and information management systems are common, healthcare knowledge, which is important for medical treatment, is rarely integrated in supporting healthcare processes. It has been recognized that integration of knowledge into institutional workflows can help to improve the quality and efficiency of healthcare delivery system [4].

In this paper, we introduce an ontology-based framework based on knowledge engineering approach in providing information and knowledge management to support chronic disease healthcare. Ontology is a standard form for information and knowledge modeling that can allow for automation and interoperability in various applications and systems. We present a prototype development of clinical reminder system to support diabetes healthcare. In this application, reminders can be triggered based on patient data and given recommendations from clinical practice guidelines. Finally, we discuss our implementation and some approaches of embedding clinical reminder services into existing healthcare provider applications in order to improve quality of patient care services.

## 2. Background and Framework

### 2.1 Information and Knowledge Management to Support Chronic Disease Healthcare

The Chronic Care Model (CCM) is a guide to higher-quality chronic illness management in patient care [2]. The model recommends that improving six interrelated components — self-management support, clinical information system, delivery system redesign, decision support, health care organization, and community resources — can result in a more effective system in chronic care management. These components aim at producing more informed and knowledgeable patients and healthcare providers. This can result in more productive interactions between them and thus can potentially improve the quality of care and outcomes.

In our framework, we focus on providing information and knowledge management support for two CCM com-

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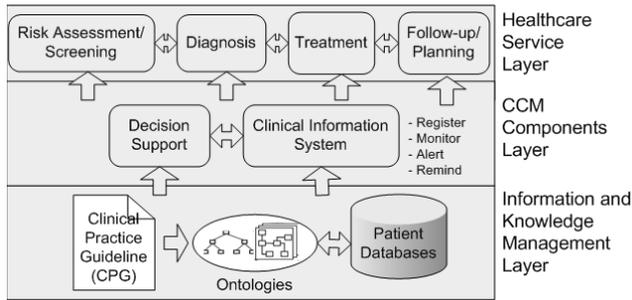
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**Fig. 1** A layered architecture for knowledge-based chronic care components.

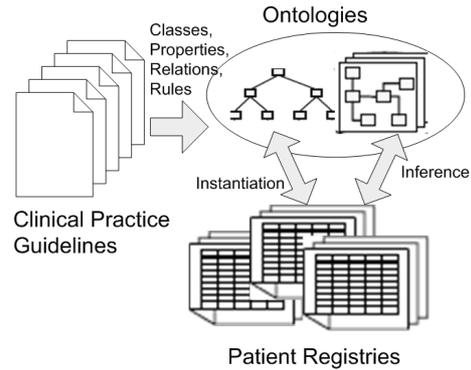
ponents: decision support and clinical information system. The two components can be summarized as follows:

- **Decision support.** The component focuses on embedding evidence-based guidelines, i.e. clinical practice guidelines (CPG), into daily clinical practice. Evidence-based guidelines normally integrate specialist expertise and are based on proven research studies and results, i.e. evidence-based medicine (EBM).
- **Clinical information system.** The component focuses on utilizing information management system in supporting healthcare process. This include developing patient registries, automatic alerts/ reminders for preventing malpractice and monitoring for improving performance of practice team and care system.

In the Diabetes Healthcare Knowledge Management project, we emphasize the need for healthcare knowledge management [4] to support diabetes healthcare processes. Knowledge captured from clinical practice guideline (CPG) should be embedded into healthcare applications to assist healthcare providers’ decision making. The guideline knowledge should also be integrated with existing hospital databases, e.g. patient registries. For example, based on a patient’s clinical data, a clinician may be automatically reminded about the routine examinations that the patient should receive based on the medical guideline recommendations. Together, they allow for knowledge-based chronic care components that provide support for diabetes healthcare processes. Figure 1 shows a layered architecture for knowledge-based chronic care components to support diabetes healthcare processes.

## 2.2 Ontology-Based Information and Knowledge Management Framework

In computer science, ontology is a controlled vocabulary that describes objects and the relations between them in a formal way. Ontologies provide a sound basis for sharing domain knowledge between human and computer programs, or between computer programs. An ontology normally defines concepts (or classes), individuals (or instances), properties, relationships and their constraints. Logical formalization of ontology language ensures semantic interpretation, i.e. inference, by computer programs. Ontology is a



**Fig. 2** Relationships between ontologies, patient registries and clinical practice guidelines.

major instrument toward realization of the Semantic Web vision [5].

In our framework, ontology-based information and knowledge management [6] focuses on providing information and knowledge support for chronic care services. The framework focuses on integration of three forms of information and knowledge: patient registries, clinical practice guidelines and ontologies. The ontology-based framework allows various forms of data to be integrated and associated with the ontology-based knowledge structure [7]. In our project, ontologies provide a means for knowledge acquisition and modeling of the relevant healthcare knowledge. Specifically, ontology is developed based on translation of existing clinical guideline documents. The developed ontology defines common structural schema that can be linked with data in patient registries, i.e. using concept instantiation mechanism. It can also contain sets of production rules that represent decision models and recommendations defined in the clinical guideline to support inferences. Figure 2 shows relationships between ontologies, patient registries and clinical practice guidelines in this framework.

Although ontologies can be advantageous in numerous ways [8], we emphasize the benefits of ontologies in supporting chronic care services in terms of providing automation and interoperability in clinical information systems.

- **Automation.** Medical personnel are often overloaded by daily tasks and activities. In addition, they are often overloaded by large volume of patients’ data. Ontologies can facilitate automated and intelligent processing of data. Such automation embedded in healthcare applications can provide assistance to the human medical personnel to reduce their workload and improve reliability, i.e. reduced errors. It should be emphasized that providing such automation will not replace human medical personnel but rather to assist in their routine tasks.
- **Interoperability.** Clinical databases are often different both in terms of database schema and terminologies. Such heterogeneity makes it difficult for sharing and integration of existing healthcare data. Ontologies can define common structure and meanings, i.e.

semantics, which can be shared and reused across systems. Different database schema and used terms can be mapped into common structure and vocabulary that is defined using a standard ontology format. Specifically, the Web Ontology Language (OWL)<sup>†</sup> is the standard interchange format for ontology data that uses XML syntax.

### 3. Ontology Development for Diabetes Mellitus Clinical Reminder System

#### 3.1 Related Works in Diabetes Mellitus Ontology Development

There have been several attempts to develop diabetes mellitus (DM) related ontology. Shahar et al. [9] developed a general method called knowledge-based temporal-abstraction (KBTA) and focused on representation for reusable and shared knowledge. Ganendran et al. [10] developed an ontology-driven multi-agent system that applied to diabetes management case study. The system provided communication among three agents, specialist agent, patient agent and WWW agent. Lin and Sakamoto [11] defined the ontology of glucose metabolism disorder (OGMD) that can be combined with the ontology of geographical regions (OGR) and the ontology of genetic susceptibility factor (OGSF) in describing the genetic susceptibility factors to diabetes mellitus. The ontology of glucose metabolism disorder includes the disease names, phenotype and their classifications involved in glucose metabolism disorder.

To the best of our knowledge, none of the existing ontologies was designed to support reminding activities that are related to screening, diagnosis, treatment or follow-up activities. Therefore, we attempted to define a new DM ontology to provide support for these tasks in DM healthcare focusing on reminding activities.

#### 3.2 Diabetes Mellitus Healthcare Ontology Development

Our DM healthcare ontology development effort relied on expert opinions in form of clinical guidelines. Clinical guideline recommendations are normally provided based on the best available evidence. Thus, ontologies developed based on the guidelines typically represent reliable knowledge and are agreeable in terms of expert opinions. In developing the ontologies, the clinical guideline for diabetes care issued by Thailand's Ministry of Public Health was translated from free text into a formal representation using the knowledge engineering approach.

The DM healthcare ontology was designed and developed by a team of knowledge engineers and medical experts, i.e. medical doctors and public health specialists, using ontology development tools. Two forms of knowledge are distinguished: structural and procedural knowledge.

**1. Structural Knowledge.** This knowledge type allows

the computer to be able to make use of patient's clinical data. Thus, the knowledge provides structural information, i.e. schema, of patient's clinical data. This includes personal data, assessment and therapeutic data and history, which are critical for decision support and clinical information systems. OWL and RDF standards are utilized in defining structural knowledge and its instantiation respectively.

**2. Procedural Knowledge.** This knowledge type represents the guideline recommendations that help to support decision making in medical diagnosis, treatment and planning processes. This process-oriented knowledge together with the patient's clinical data will assist the healthcare providers to make well-informed decisions that are based on evidence-based guidelines.

#### 3.3 Ontology Development Process

One of the main goals in our DM healthcare ontology development was to provide support for healthcare providers and applications that supported their service activities. The ontology was designed based on 1) the 2008 Diabetes Mellitus Clinical Practice Guideline issued by the Thailand's Ministry of Public Health, which has been widely used as reference for guiding decisions regarding diagnosis, management, and treatment of diabetes mellitus and 2) discussions with the physicians and specialists to verify the correctness. The ontology development process was based on the methodology defined by Noy and McGuinness [12], which can be elaborated as follows.

##### 1) Defining the Scope of DM Healthcare Ontology

There are mainly two approaches in defining the scope of an ontology: bottom-up and top-down approaches. Our development combines both approaches. We utilized the bottom-up approach by investigating patient's paper-based records, such as those available in outpatient department (OPD) card. This approach must rely on evidences from existing information resources in some provider settings. However, the reliability and acceptance of such knowledge must be carefully verified. We utilized the top-down approach by using the CPG as the major reference. Our scope was limited to Type II DM and four main related complications: diabetic retinopathy, neuropathy, nephropathy and foot.

##### 2) Defining the Classes and Class Hierarchy

In this step, we listed important terms from the CPG and conceptualized these terms into classes and their relations in terms of class hierarchy. The Hozo ontology editor<sup>††</sup> was mainly used in facilitating this task. A class is normally defined along with its "part-of" relations and "attribute-of" relations. For example, in Fig. 3, the "Patient" class which represents a patient record consists of three part-of relations with three major classes: "Person" class, "Status" class

<sup>†</sup><http://www.w3.org/TR/owl-features/>

<sup>††</sup><http://www.hozo.jp/>

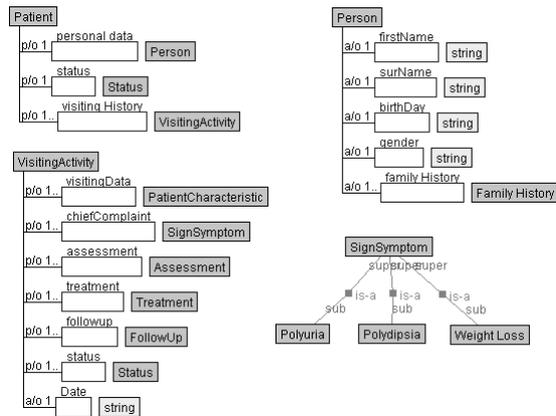


Fig. 3 Defining class and class hierarchy in the DM healthcare ontology.

and “VisitingActivity” class. The “Person” class consists of some attribute-of relations such as firstname, surname, birthday, gender and family history, etc. The “Status” class represents the patient’s DM and complications diagnosis results. The “VisitingActivity” class contains the activities and results of each visit of a patient as follows:

- Date of visit
- Signs and symptoms
- Treatment activities such as medication, and procedure (e.g. amputation)
- Assessment activities such as physical examinations and laboratory examinations
- Follow-up activities such as eye examination within next three months
- Status which shows DM and complications diagnosis after each visit

We applied the “IS-A” relation to define class hierarchy. For example, we defined a class hierarchy of “Examination” class into four subclasses: physical, radiograph, electrograph and clinical laboratory examinations. Physical examination is the process that a healthcare provider measures and monitors signs of disease from the patient’s body, such as temperature, blood pressure and heart rate. Radiography applies X-rays to capture image of internal organs. Electrograph uses electromagnetic to monitor organ mechanisms into wave form such as Electrocardiogram (ECG) which is used to monitor heart rhythms. Clinical laboratory examination involves human specimen examination results. Currently, our DM healthcare ontology consists of approximately 220 defined concepts.

### 3) Creating Instances

There are typically two methods in creating instances for ontology classes, i.e. instantiation process. The first method is to manually construct an instance and define its attribute values based on a class. This is typically done using instance editor provided in ontology development tool. The second method is to create instances from some existing information sources, such as database records. This normally requires the mapping process between the existing database

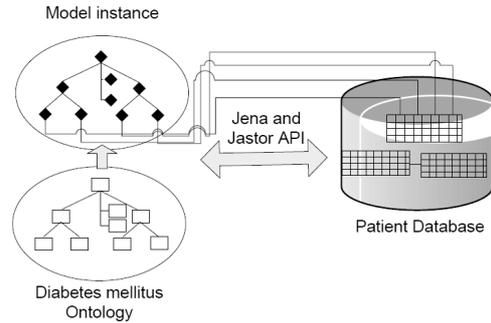


Fig. 4 Framework for mapping patient database to ontology instances.

schema and ontology structure. After the mapping process, a database record can be properly transformed into a class instance. This method is most suitable when an organization already stored the data in some databases. We applied the second method in creating instances since most of the patient data were already stored in some hospital information systems. Several ontology application programming interfaces, such as Jena<sup>†</sup> and Jastor<sup>††</sup> API, can be utilized in this step as shown in Fig. 4.

## 4. Implementation of Clinical Reminder Knowledge Service

### 4.1 Web Service Architecture

Some of the main challenges for health information systems include redundant data and functionality, heterogeneous technologies and the lack of reuse [13]. Service-oriented architectures (SOA), i.e. Web service, offers a framework and implementation that promotes interoperability, integration and reuse of data and functionalities that has potentials of being applied to the healthcare domain [14], [15]. We adopted the Web service architecture in implementing clinical reminder system as a medical knowledge service. This section describes our SOA-based implementation of the clinical reminder knowledge service using the UML 2.0 notation schemes.

Figure 5 shows a use case diagram of the clinical reminder knowledge service. The service consists of two main actors: client system, which represents any hospital with patient database, and doctor from the client system side. The diagram illustrates four use cases of the system. First, the client system can authenticate and connect to the system in order to be able to perform the desired task which is shown as “Register Patient Data” use case. The second use case is related with getting reminder results based on the patient’s recommended examination dates (“Remind Examination Date”). The third use case is related to getting recommendation messages based on the patient clinical data. (“Get Recommendation”). The final use case is related to obtaining alerts when the patient’s clinical data contains ab-

<sup>†</sup><http://jena.sourceforge.net/>

<sup>††</sup><http://jastor.sourceforge.net/>

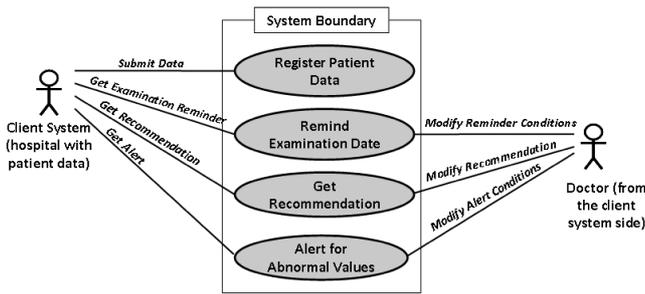


Fig. 5 Use case diagram of the clinical reminder knowledge service.

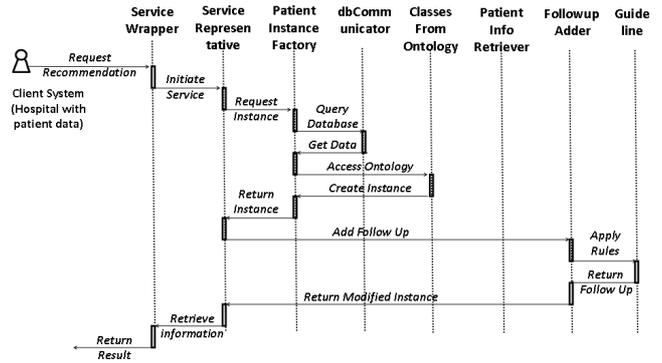


Fig. 7 Sequence diagram of the clinical reminder knowledge service.

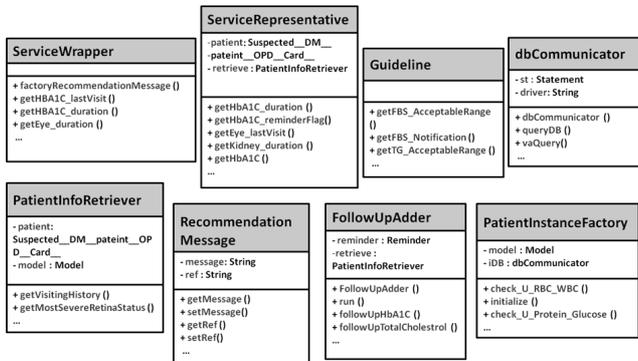


Fig. 6 Class diagram of the clinical reminder knowledge service.

normal values (“Alert for Abnormal Values”). The last three use cases can be applied by both of the actors involved in the system. The client systems obtain the results from the knowledge service while the doctors can modify and adjust the knowledge to their specific needs.

The service class diagram, which consists of eight main classes, is shown in Fig. 6. The “PatientInstanceFactory” class is responsible for creating patient instances from patient’s records of the given database. The “PatientInfoRetriever” class is responsible for retrieving the data from the created patient instance. It is used by two classes: “FollowUpAdder” which applies the rules to determine which follow-up-related objects should be added to the given patient, and “ServiceRepresentative” which acts as the main gateway to call every service. “dbCommunicator” is the middle agent between database server and other classes which requires retrieval of the data. The operations of this class perform two common steps: get the database schema to ontology mapping configuration and get the actual data from client’s database server. “Guideline” provides the recommendation values based on CPG recommendations. The “RecommendationMessage” class acts as a data exchange manager between the client system and the web service. Finally, the “ServiceWrapper” class is the web service interface which contains all the operations of the service that can be invoked by standard web service invocation methods.

Figure 7 shows a sequence diagram which exemplifies chronological messages passed between the components. This can be conceptually described as followed.

1. The client system requests for recommendation for a patient from “ServiceWrapper” which subsequently call “ServiceRepresentative” to request the patient instance.
2. “PatientInstanceFactory” creates a patient instance.
3. The class makes use of “dbCommunicator” in querying the database to get the patient’s information
4. The class makes use of the ontology classes which were previously created as Java classes using the Jastor API
5. “FollowupAdder” adds the follow up instances, created based on the obtained results from “Guideline”, to the created patient instance (from step 2) and return the modified patient instance back.
6. The patient recommendations can be obtained from the returned patient instance. The retrieved results are subsequently returned to the client system.

#### 4.2 Database Schema to Ontology Mapping

Schema mappings are widely used in data management applications that involve data sharing or data transformation [16]. Schema mappings generate specifications that describe the relationships between schemas at a logical level without involving implementation details. In our implementation, schema mapping helps to reduce the complexity and programming effort of the client applications which must exchange and share the patient data with the web service. In our mappings, source schema is Relational Database Management System (RDBMS) schema while target schema is the DM healthcare ontology. The ontology serves as the unified information representation that can be shared among heterogeneous healthcare data sources and applications [17]. Put another way, mapping source schemas to ontology makes it possible for the web service to understand the data from different sources.

Figure 8 shows a user interface of the database schema to ontology mapping tool whose usage can be briefly described as follows. In order to use the web service, the client system must define mappings for all the necessary fields. The table shows a list of already mapped fields while the highlighted rows are yet to be matched. In addition to column-level mapping, specific information about the client database and tables involved in the mapping, e.g. authentica-

tion data, keys, etc., must also be provided in another interface. The mapping tool produces a mapping definition [18]. This mapping definition is then used by the web service to automatically transform the source database records into instances of ontology classes.

4.3 Knowledge Maintenance Using Rule Editor

In implementing clinical reminders, maintaining rules separately from the program has benefits both in terms of reducing errors from out-of-date knowledge and maintenance effort [19]. Specifically, utilizing external rule editors allows greater control over the reminder knowledge modification process, reduces the time for modifying rules, and makes the programming logic transparent to the domain experts. There are two approaches in utilizing rule editors: using generalized rule editor such as the SWRL rule editor of Protege<sup>†</sup> [20] and application-specific rule editor, such as a clinical reminder rule editor [19]. We adopted the latter approach by implementing an external clinical reminder rule editor. This was to allow for a more user-friendly interface design and better support for our designed use cases for the domain experts.

Figure 9 shows a user interface design of our clinical reminder rule editor. The rule editor has two main editing steps: one is creation of atomic term and another is rule composition. In order to create a rule, user has to perform both of the steps. For example, a defined rule to generate recommendation for a patient with high level of blood sugar or lipid profile can be composed. In composing this rule, the user creates three atomic terms based on the defined ontology terms: “HBA1C > 6.5”, “FBS > 110” and

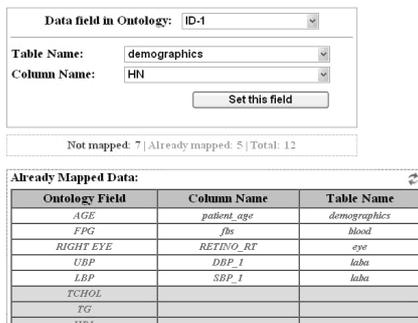


Fig. 8 A user interface of database schema to ontology mapping tool.

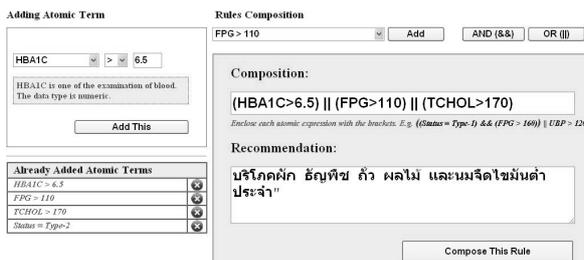


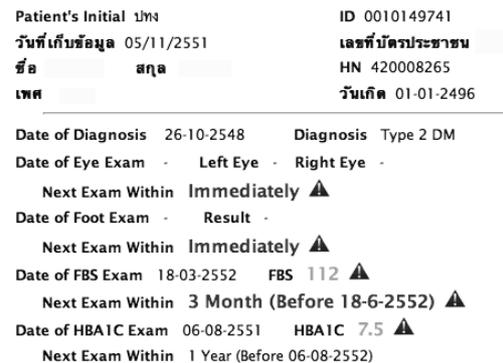
Fig. 9 A user interface of clinical reminder rule editor.

“TCHOL > 170”. Subsequently, a composition is created as “(HBA1C > 6.5)||(FBS > 110)||(TCHOL > 170)”. Finally, the user specifies the recommendation text message to be returned when this condition is matched.

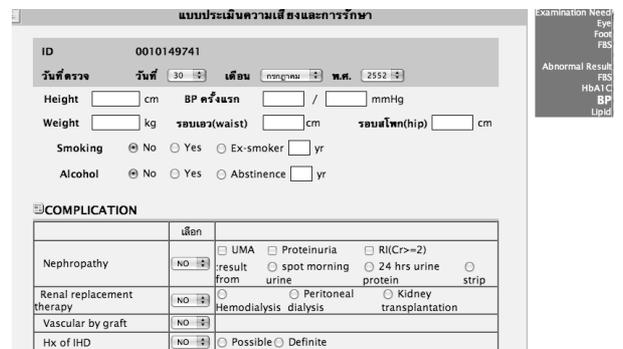
5. Approaches to Integrating Clinical Reminder with Patient Registries

One of the challenges is to apply reliable knowledge into existing healthcare provider environments by focusing on augmenting decision making and improving quality of patient care services. The healthcare knowledge management approach [4] focuses on embedding knowledge into the clinical work environment that would not require the providers to explicitly request for, i.e. using automatic alerts and reminders. Medical errors and omissions in healthcare process may be minimized by means of detection and prevention. For example, based on medical knowledge from the guideline, an automatic reminder may be triggered when a patient has not received some recommended tests within some recommended periods. Alerts can be triggered to inform the provider when the patient’s lab test data is above or below recommended values, which may affect the clinician’s decision making.

We adopted two approaches to embedding alert/ reminder service into existing diabetes patient registries: offline and online reminders. Figure 10 shows a design of



(a) Offline alerts/reminders embedded in a diabetes patient registry.



(b) Online alerts/reminders embedded in a diabetes patient registry.

Fig. 10 Two approaches to embedding alert/reminder service into an existing diabetes patient registry.

<sup>†</sup>http://protege.stanford.edu/

**Table 1** Evaluation results of the reminder functions.

Evaluation Criteria	Avg. Score (SD)	% of neut. or pos. res.	% of pos. res.
<b>Clarity and Intuitiveness</b>			
offline reminders	3.30 (0.66)	90%	40%
online reminders	3.15 (0.67)	85%	30%
<b>Usefulness and Adequacy</b>			
offline reminders	3.75 (0.64)	100%	65%
online reminders	3.55 (0.76)	90%	60%
<b>Overall Satisfaction</b>	<b>3.60 (0.50)</b>	<b>100%</b>	<b>60%</b>

alert/ reminder service added to an existing diabetes patient registry system, i.e. the DMSDD system, a diabetes patient registry software released by the Department of Medical Services, Ministry of Public Health. Figure 10(a) shows embedding alert/ reminder service in an offline fashion in form of a patient data report which can be viewed by medical personnel. The report includes alerts and reminders for some recommended tests and some lab test results that were above or below the recommended values. Figure 10(b) shows embedding alert/ reminder service in an online fashion. Alerts/ reminders are shown as pop-up notification messages while the medical personnel are working with the patient data.

## 6. Evaluation

An assessment of the embedded reminder functions was conducted in terms of presentation clarity and intuitiveness and information usefulness and adequacy. The functions were assessed by 20 medical personnel who were from ten different hospitals and healthcare providers that have used the diabetes registry software. The purpose was to examine whether the embedded reminder functions could achieve a satisfactory level in supporting the user tasks. The users were asked to rate their satisfaction in the scale of 1 (highly disagree) to 5 (highly agree) given the evaluation criteria for both the offline reminders, i.e. reports, and the online reminders, i.e. pop-up messages, as well as the overall satisfaction.

The results, summarized in Table 1, are shown in terms of average rating score, percentage of neutral or positive responses (rating score of 3, 4, or 5) and percentage of positive responses (rating score of 4 or 5). The user satisfaction levels for the offline reminders were slightly higher both in terms of clarity and usefulness. The overall user satisfaction was in a moderately high degree (avg. = 3.6, SD = 0.5) with 60% of positive responses. The user comments were generally related to when and how the information should be delivered to the patients and suggested linking with patient education.

## 7. Conclusion

In this paper, we describe an ontology-based information

and knowledge management framework that is important for chronic disease care management. The framework is designed to support two chronic care components: decision support and clinical information system. The framework focuses on building of healthcare ontology and clinical reminder system that link clinical guideline knowledge with patient registries to support evidenced-based healthcare. An implementation based on the Web service architecture is utilized to promote reuse and interoperability. We present approaches in integrating clinical reminder services to existing healthcare provider environment in order to help improving quality of patient care. Our future work will focus on incorporating some electronic health record (EHR) standards including HL7.

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