Ontology Driven Cardiovascular Decision Support System

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Abstract—This paper presents an ontology driven framework for the development of a clinical expert system targeted for chest pain risk assessment. The proposed ontology driven framework will deploy key components (adaptive questionnaire, patient medical history, risk assessment and decision support capabilities) which can be reused for other areas thus accomplishing a decision support system capable of handling a range of cardiovascular diseases. The adoption of ontologies in healthcare has facilitated domain experts and non experts to perform knowledge representation tasks with great ease and without requiring any computer programming knowledge. The organization of medical knowledgebase is no longer laborious and costly business. The primary and secondary care clinicians adhere to certain specialized healthcare knowledge bases such as NICE (National Institute of Clinical Excellence guidelines in UK) in order to diagnose chest pain efficiently and also to mitigate risk of Heart attack in patients at early stages. They also store the episodic information for future reuse and for auditing purposes. Healthcare information management systems for primary and secondary care are expected to be able to communicate and exchange complex medical knowledge (often expressed in numerous languages in different parts of the world) in an efficient and unequivocal way. For the purpose of this research project we are developing a decision support system using multiple chest pain assessment guidelines for UK and US healthcare authorities. These include NICE, AHA (American Heart Association) ACC (American College of Cardiology) and SIGN (Scottish Intercollegiate Guidelines Network).

I. INTRODUCTION

Coronary heart disease (CHD) is the most common cause of death in the UK, and the death rate in the UK is still higher than many European countries. Approximately 2 million people are currently living with angina in the UK. [http://www.heartstats.org]. This condition is associated with an annual mortality between 2.8% to 6.6% per annum [1]. The incidence of angina and acute coronary syndromes has been shown to vary according to risk factors such as age, gender and ethnicity.

Patients who present with chest pain continue to present a major diagnostic challenge for both primary and secondary care physicians. This is due, in part, to the low specificity of chest pain as a symptom of significant coronary artery disease and the danger of misdiagnosis in patients at risk of major cardiac events. Furthermore, chest pain is a very common symptom, between 20% and 40% of the general population will experience chest pain in their lives [2] with up to 1% of visits to a general practitioner due to chest pain [3]. Chest pain is also common presenting complaint in patients attending A and E accounting for approximately 5% of visits to the emergency department. Furthermore, up to 40% of emergency hospital admissions are due to chest pain [4].

Even when patients are reviewed in the hospital setting with relatively easy access to diagnostic tests, it is estimated that between 2-5% of acute myocardial infarction patients are discharged inappropriately in the United Kingdom [5]. These individuals often have a very poor outcome, and are a leading cause of malpractice lawsuits each year [6].

A. Rapid access chest pain clinic

In 2001, the National Service Framework for Coronary Heart Disease made a commitment to have 50 rapid access chest pain clinics (RACPC) in England by April 2001 [DOH 2000]. These clinics were designed to allow direct access to cardiology expertise without the need for accident and emergency assessment or admission to a medical ward. RACPCs would appear to be reliable and safe in the assessment of patients with suspected cardiac chest pain. [7].

B. Clinical Guidelines

Several clinical guidelines exist for the management of patients with chest pain. [SIGN, ACC] and more recently, NICE published guidelines for the management of recent onset chest pain. [5] However, producing clinical guidelines is not sufficient and implementation of guidelines presents a significant challenge. Several barriers to implementation of guidelines exist throughout the patient pathway, from problems with delayed referral, limited access to specialists and to specialist tests and rationing of some treatments. It remains difficult to ensure that all health care professionals are aware of new guidelines and implement them. This results from ever increasing demands on healthcare professional’s time and increasingly complex treatment regimes for patients. This is particular problem for general and primary care physicians who are required to maintain a breadth of skills and knowledgebase in a number of areas of medicine. Enforced embedding of clinical guidelines or clinical care pathways into paper or electronic referral systems is one approach to overcoming these barriers.

C. Accessing Patients with Chest Pain

Clinical Features
There are several stages in the management of patients with suspected cardiac chest pain. The initial assessment should determine if it likely that this patient is describing chest pain of a cardiac origin. This requires knowledge of the clinical history and risk factor profile of the individual patients. Given how common chest pain is, and how non-specific the symptoms can be, the ‘pre-test’ probability of the presence of significant CASD for each patient is of crucial importance. There are several algorithms that can be used to assess this. The algorithm used in the recent NICE guideline is based on the age, gender, risk factors and the typicality of the chest pain [8].

D. Diagnostic Tests
A resting ECG should be performed promptly in all patients complaining of chest pain. In order to further assess the patient further there are a range of available diagnostic tests including non-invasive functional testing (such as exercise ECG, stress echocardiography, myocardial perfusion scanning, and stress MRI [9] or anatomical testing such as CT coronary angiography [10] or conventional diagnostic coronary angiography. Which test used will depend on each individual patient but also in part the relative availability at a local level.

E. Treatment
Treatment usually always involves medication but may also involve more invasive strategies such as coronary artery stenting and coronary artery bypass surgery. The timing of treatments and need for invasive treatments such as stenting or coronary artery bypass grafting requires to be assessed on a case by case basis and decision making can be complex.

From the above discussion, the following problems can be identified in the context of diagnosing and managing the risk of chest pain.

1. Lack of adaptive intelligent patient clinical information gathering systems that enable gathering of all the relevant history of patients.
2. As a result of the above, clinicians may make referrals errors which could either lead to a waste of the secondary care resources or leave patients at risk if a referral is not made.
3. Lack of patient’s medical history (Cardiovascular and Family history, Cardiac risk score) for the assessment of heart conditions like chest pain.
4. In the conventional healthcare systems, patients have not been made proactive by making them involved in the decision making process. The IT healthcare systems should work with the patients as oppose to working for the patients.

The problems at hand can, in general, be solved by developing ontologies for specific medical domains for representing domain expert knowledge [11]. The primary and secondary care information management systems can be made flexible, more adaptable, and interoperable. The aim of this study is to develop standardized domain specific ontologies in the field of cardiovascular domain, with a case study focusing on risk assessment and management of chest pain.

The rest of the paper is organized as follows:
Section 2 reviews the state of the art in patients interviewing systems and section 3 gives an overview of the strategy employed in these systems. Section 4 presents our proposed ontology driven approach and its application to chest pain assessment is discussed in section 5. Ongoing and future work proposals are presented in section 6 and some concluding remarks are finally given in section 7.

II. OVERVIEW OF CURRENT PATIENTS INTERVIEWING SYSTEMS
This research will focus on the comparative study of traditional patients interviewing systems which are based on conventional hard-wired branching logic. These systems have significant limitations, including: lack of flexibility and adaptability to complex requirements and processes and a general lack of astuteness [12]. These interviewing systems do not go far beyond core functionalities and due to their rigid architectures, these conventional systems are hard to maintain and update [11]. We are trying to solve such knowledge representation issues using domain specific Ontologies which can offer powerful and appealing solution to these problems.

A. Computer based Screening/Interviewing systems
Computer-based screening systems have had measurable benefits in reducing omission and errors arising as a result of clinicians dealing with information of high complexity. As an example, diagnosis systems have proved useful in error prevention and preventive intervention through the use of structured entry, rule-based reminders and triggering of alerts relating to allergies, drug doubling, contraindications and adverse drug interaction. Likewise, in his survey of patient-computer interview systems, Professor Warner Slack at Harvard Medical School highlights that face-to-face information collection with a clinician is often less complete than computer-based history taking [13].

III. STRATEGY ADOPTED IN THE CURRENT SYSTEMS
In a primary care setting, GPs often refer patients with suspected cardiac chest pain to a Rapid Access Chest Pain Clinics in Secondary care which are often nurse-led clinics. Primary care clinicians, in this case GPs, have to assess patient as per the (Cardiology clinic) guidelines before they are put through to secondary care chest pain clinics for further examination. The RACPC service only accepts referrals where certain medical conditions are met to ensure patients suitability for these clinics. These systems are not centralized and very much paper based. Patients’ full medical history is not available at the time of assessment for both primary and secondary care clinicians which may make it challenging to make the right judgment for the patients.

IV. ONTOLOGY Driven approach
The adoption of Ontologies inspired approach yields good results in terms of standardizing healthcare guidelines. All decision support systems require some form of language
representation to encode domain knowledge and their interactions. In this publication we discuss the creation of an ontology driven decision support system for chest pain management in the cardiovascular domain. The construction of knowledgebase through an ontology will have the benefit of problem independence. This knowledgebase can be extended and reuse in a variety of different problems and therefore will have multiple mapping among knowledgebase and decision models. The knowledgebase will update the decision models without any costly software engineering work and maintenance will be cost effective across decision models and within the knowledgebase. We are using this approach for the development of a decision support system as a supporting tool for Primary and Secondary healthcare clinicians. Ontology inspired approach helps in knowledge structuring which also facilitates system developers and domain experts to acquire knowledge, reuse and ensuring knowledge consistency within the knowledgebase.

A. Benefits of Ontologies Driven systems

The focus of our discussion is on the current strategy which is to use ontologies for adapted information collection and patient representation. Using ontologies is a pragmatic solution to implementing a shift from simple management systems into intelligent systems in healthcare [11]. These systems will effectively support clinicians in their day to day operations and will yield in improved delivery of dedicated patient care. The transformation of these conventional systems into intelligent knowledge-driven systems is an iterative process which involves adding a layer of ontologies on top of the functionalities commonly required from the management system [11]. The key components of this framework are being developed using ontology driven approach for easy reuse and to provide a clear demarcation among domain ontologies and the implementation system. As part of literature review findings, ontologies required for the development of proposed decision support framework are non-existent which is why they are being developed from scratch. The proposed framework is a novel solution offering unique features. The most important features are, carrying out risk assessment using multiple risk assessment guidelines, calculating risk score using multiple risk score calculators (ASSIGN, FHS), integration with sentiment mining and opinion mining framework (to evaluate end user’s experience) , integration with MIT’s educational framework along with developing questionnaire ontology using standardised questionnaires which have been developed over the course of last 50 years by clinical informatics expert, Professor Warner Slack at Harvard Medical School. In this iterative development process, deliverables will be the development of the adaptive questionnaire, patient medical profile using OWL, chest pain classification using DL Reasoner, risk assessment, decision support capabilities and integration with third party vendors like Microsoft HealthVault repository. The integration of MIT’s multimodal conversational agent based patient educational framework will be carried out in the second stage of the development.

B. Dynamic Questionnaire

The first phase in this project is to develop an ontology driven adaptive questionnaire for Cardiovascular screening using standardised questionnaires for Cardiovascular and Family history acquired from Professor Warner Slack at Harvard. Harvard medical school agreed to provide access to the standardised questionnaires for the overall screening of patients for all the major diseases. For this publication, the focus will be on the CV and Family history knowledgebase. The questionnaire will be divided into two categories Cardiovascular and Family History as per the recommendations of NICE guidelines for Chest pain assessment which recommends that family history and cardiovascular screening/past history should be carried out whilst assessing patients for possible angina. The purpose of this context-sensitive adaptive questionnaire is to mimic the exploratory behavior exhibited by the clinicians [11]. These questionnaires will be customized to suite local UK context. The main challenge is to have an intelligent questionnaire which adapts itself as per patient’s medical history thus only asking relevant information which is pertinent to patient’s circumstances. Ontology driven approach will help us achieve the performance and scalability in our proposed system by reducing number of questions therefore making doctor-patient interaction much more interesting and cost effective. The questionnaire will be organised along semantic partitions and as per the guidelines of existing biomedical Ontologies like SNOMED CT [11].

Questionnaire ontology: The construction of domain ontologies was inspired by the ground breaking work Matt Mouley Bouamrane conducted in this area [11]. Generic questionnaire ontology will be developed using standardised questionnaires developed by Professor Warner slack at Harvard Medical School. The questionnaire ontology is presently being developed using Protégé ontology editor and OWL is used for the development of dedicated Ontologies required to implement the proposed clinical decision support framework. The main classes in the ontology are Generic questionnaire, Sub questionnaire, Start of Questionnaire, Question, The Further Question, and Answer.

Questionnaire properties. The next step consists in defining how the generic questionnaire is (i) structured and how it (ii) behaves. This is done by way of specifying properties. There
are four main properties: adaptive properties, composition properties, structural properties and finally type properties.

C. Semantic Patient Profile

In conventional system (distributed database systems), patient data held in the database do not carry any semantic meaning because of its flat structure. Patient data is often complex and diverse, often in different formats, reside in heterogeneous structures and carry different meanings. This makes the comparison, data mining and analysis of clinical data a challenging task. Most healthcare applications envisage patient data without integrating additional semantic information to understand its structure for the analysis [11]. This data cannot be used or integrated with third party healthcare vendors without costly software engineering work which often cause deployment delays and application downtimes. Matt-Mouley Bouamrane [11] suggested a solution to this problem to convert this flat structured patient’s data into semantic patient profile. The information collection based on an ontology creates the opportunity to simultaneously generate a patient profile automatically generated from the medical ontology which is to preserve the semantics in the patients’ data.

The main advantage of this approach is that a single information repository, a semantic patient medical profile, will provide access to various clients and third party APIs. This will enable us to store data in a dedicated repository, as input to a rule engine, a clinical document or a patient record for clinicians use for assessments [14], as illustrated in Fig. 1. This system design provides greater flexibility to the current implementation as new software components can be included and redundant one discarded without affecting the whole structure of the system. Profile heterogeneity is currently being considered and in order to make it compatible with other clinical information management systems, we are considering a process of mapping the concepts in the patient ontology to the SNOMED CT terminology.

Patient semantic profile ontology is currently being developed using answers acquired through adaptive questionnaire. The items of information which are relevant to clinicians consist of Boolean-type format regarding a patient’s medical history. The presence or absence of specific medical condition is represented in OWL format. Example, “has the patient got chest pain?”, “is the patient smoker? “. For this type of information, modelling is done through the use of the “hasPresence” and “hasAbsence” functional properties.

V. CHEST PAIN ASSESSMENT.

System architecture of the chest pain decision support is shown in Fig 2. The main components of the system are:

A. User Interface

In the first iteration of development patients and clinicians (possible nurses) will be provided with text enabled user interface which will be available online running from centralized servers. There will be two different entry points/user interfaces for clinicians and patients. The access to these interfaces will be granted as per role based access i.e. Patients will only be able to access patient’s interface and will not be able to gain access to the clinicians’ portal to view other patients’ data.

1) The patient’s interface

This will allow patients to take CV and family history interview in their homes at the time of convenience, prior to their appointment with primary care doctor (Cardiologist in US and GP in UK context).

2) Clinicians Interface

At the time of the patient’s appointment with the GP, the summary or the clinical notes will be available to clinicians (both primary and secondary care) through clinicians’ interface which will be username and password protected for security and data protection purposes. This will be a cost effective way of generating patient’s medical history and make it available for clinicians which they often lack at the time of consultations.

B. Knowledge Adaptation

As discussed earlier context-sensitive information will be collected using dynamic questionnaire module. Patients will be asked to sit an assessment (pre-appointment) online and answer questions pertinent to cardiovascular (CV and chest pain screening) health and general family history. The adaptive questionnaire will adapt itself as per patient’s personal medical and family history. The adaptive questionnaire will be driven through ontology driven approach thus creating a dedicated layer of abstraction for ease of use,
maintenance and deployment purposes. There will be explicit separation among core system functionalities and the domain expert’s knowledgebase used by the decision support system which means that the questionnaire ontology will be modified without costly software engineering work [12]. This system will enable clinicians to view the results of these questionnaires and benefit from the snapshot of patients medical histories for the assessment.

The decision support Ontology will consist of Risk assessment Ontology, Recommended Lab Test ontology and Prescribing ontology. The role of risk assessment ontology is to calculate risk score (Cardiac risk score index using Framingham and Assign risk Score algorithms). Also to assess patients belong to different chest pain categories (as per chest pain classification performed through NICE, ACC and SIGN guidelines) for coronary angiography treatments in line with the clinical pathway set out in RACPC guidelines. Decision support ontology performs following operations. Risk assessment: The purpose of risk assessment is to highlight potential risks and complications given a patient semantic profile. The second one is the “Recommended Test Ontology” which is being developed to suggest certain lab tests which may further help to decide whether patient is suitable for a particular treatment e.g. coronary angiography.

C. Data Repository

Patients’ medical histories will be stored in a dedicated DB repository to calculate CV risk score using Framingham and Assign risk score calculators. This data will also be used for statistical analysis, data mining and generating electronic health records for the patients.

D. Chest Pain Classification and Clinical Rules

There is a strong clinical case for choosing to run different chest pain assessment guidelines depending on the specifics of a patient or a particular procedure. Chest pain classification will be carried out using NICE, ACC and SIGN guidelines. Clinicians will be able to select risk assessment standard of their choice for carrying out chest pain risk assessment and classification in terms of categorizing patients in a relevant chest pain category. The classification of the patients with suspected angina will be carried out using Pellet (to reason on the decision support ontology using patient semantic profile) which is OWL based dynamic logic reasoner.

E. Decision Support Ontology

Decision support ontology is currently being developed according to clinically validated, published, best-practice evidence-based clinical guidelines in chest pain risk assessment. Decision support ontology will be developed using NICE, ACC and SIGN guidelines and is regularly peer reviewed by consultant cardiologist in the United Kingdom. The purpose of the decision support system is to lend helping hand to primary care and secondary care clinicians by providing them a novel functionality to select risk assessment of their choice (as per the geographical and clinical needs) from multiple risk assessment guidelines. This will be one of the unique features of the decision support framework which will make it possible for the healthcare service providers to deploy this clinical decision support system in different healthcare settings in UK and US.

Figure 2. Chest pain Decision Support System for Primary and Secondary Care

Figure 3. RACPC Clinical Pathway
Prescribing Ontology

This ontology will be used to prescribe drugs to the patients with (probable or possible) angina chest pain patients keeping in view their Cardiac risk score, Chest Pain Classification and RACPC risk assessment results. Patients with low cardiac risk score, no family CV history and at early stages of heart disease could be dealt with by way of prescribing Statin, Aspirin etc.

VI. FUTURE WORK

A. Data Driven Prediction Systems

A novel ontology driven data mining approach will be developed to perform data mining using clinical datasets for patients undergoing treatment for chest pain and palpitations. An additional novel approach will be developed for predicting patients at high absolute risk of developing coronary heart disease in the next 10 years using Bayesian Network. The results obtained through the Bayesian classifier will be compared with methods using a standard logistic regression model. These predictability models will be developed using real patients data acquired through Raigmore Hospital in UK.

We are building a clinical information collection system specifically for this purpose which will enable us to gather patients' data from hospitals in UK and US. We will apply data mining techniques to predict clinical outcomes and develop new prediction models for chest pain, palpitations and other conditions in cardiovascular domain.

B. Opinion Minning and Sentiment Minning Techniques

Opinion and sentiment mining techniques (which have already significantly extended the traditional 'common sense computing/machine learning' tools developed by our collaborators in MIT Media Lab) could allow us to collate and 'make more sense' of patients' unstructured evaluation (expressed in free/natural language) of our developed ontology-driven e-healthcare system, and that, in turn, could help us correlate the unstructured feedback with 'traditional' structured evaluation of the system), with the structured external evaluation of those healthcare providers/hospitals that has been independently carried out by NHS Trusts (in the UK). The (interesting) results are currently being reported in journals.

C. MIT’S Multimodal conversational agent based Patients educational framework

In the final (commercialization) phase of development, this ontology driven framework will be integrated with an innovative multimodal affective human-computer interface (that is being separately researched and developed at Stirling's COSIPRA Lab in collaboration with MIT Media Lab - with complementary goals of enhancing the doctor-patient collaboration and better informing and educating the 'patient of the future'). The aim is to enable a more modern collaborative and continuous approach to care by facilitating new paradigms in doctor-patient relationship. It allows patients to become active participant in their care through data transparency, shared decision making, education and new channels of communication. The end prototype will be integrated with Dr John Moore’s educational framework which is to validate the functionality of the prototype and also to include additional functionality offered by MIT’s network.

1) Some of the features offered by MIT’s framework

a) Auto generation of decision trees to explain clinical reasoning

This functionality will be offered in quest of educating patient of the future and to make them aware of the clinical workflow which is followed (encoded as per clinical guidelines) by the expert system for clinical decision making especially for the recommendation of lab tests, drugs prescription etc. This functionality is achieved by way of deploying decision trees for continuously extracting the clinical reasoning in the form of medical expert’s actions that is encoded within the expert system and in the large EMRs (Electronic Medical records). In this way the extracted data could be used to educate patient of the future.

b) Provide time line series of medication

This framework provides a visualization environment for chronic diseases management especially providing visibility over personal medication histories. A Flex based client is being developed, which acts as the visualisation front end for the patients. This interface presents a one-screen overview of patient’s medication using timelines. Problems, diagnoses, test results or medications can be represented as dots or horizontal lines. Zooming (zoom in and out) provides more details; line colour and thickness illustrate relationships or significance. It is designed to easily collaborate with patients. In the next stage of development, further intelligence will be built into the system and focus will be on developing diseases/problems forecasting capabilities. It is very practical and very much UI driven solution for chronic diseases management. This framework will be integrated with personal health records systems. The business services are designed in a way to allow integration with third party vendors like Google health and Microsoft Healthvault. This framework is currently being developed using open source Indivo database.

VII. Conclusions

We have presented an ontology driven approach for the development of a cardiovascular decision support system focusing on chest pain risk assessment. This approach has also paved way for the automation of RACPC service which is very much paper based and led by cardiology nurses in most of the hospitals in UK. The proposed system will be able to replace existing RACPC service in major cardiology clinics in UK. The main advantages of the ontology driven approach are as follows:

This allows cost effective maintenance of the CDSS because of a clear demarcation among knowledgebase and decision
support functions. Ontology layer enables the system to perform decision support operations which are hard to implement using distributed system technologies and centralized databases. This approach also facilitates us to follow a generic component based approach for the reuse and extension of this decision support system to include other diseases in the cardiovascular domain and automate conventional paper based clinics.

A. Abbreviations and Acronyms

NICE: National Institute of Clinical Excellence
ACC: American College of Cardiology
SIGN: Scottish Intercollegiate Guidelines Network
Rule Based Access: Hierarchical Security access granted as per user’s role profile within the organization
SNOMED CT: Systematized nomenclature of medicine clinical terms is a clinical terminology with comprehensive scientifically valid content.
ESPRC: Engineering and Physical Sciences Research Council
OWL: Web ontology language
GP: General Medical Practitioner
CDSS: Clinical decision support system

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