Towards sustainable decision-support system facilitating EBM

Nevena Stolba, Tho Manh Nguyen, A Min Tjoa

Abstract— **Due to the immense volumes of medical data, the architecture of the future healthcare decision support systems focus more on interoperability than on integration. With the raising need for the creation of unified knowledge base, the federated approach to distributed data warehouses (DWH) is getting increasing attention. In this paper, we explore the idea of a federation technology and its uses within the domain of health, particularly in the conceptualization of DWH federation as a sustainable, appropriate and legitimate solution. Further, we present a federated DWH model which enables the interoperability between heterogeneous and distributed medical IS, which includes a sense and response mechanism and facilitates evidence-based medicine in order to primarily support the physicians at the point of care. A real-world scenario illustrates a possible application field in the area of emergency and intensive care.**

I. Motivation:

EVIDENCE-BASED medicine (EBM) is the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients [12]. It contributes to the decrease of variance in medical decision making, leading to the improvement of clinical outcome. The combination of DWH, data mining and EBM is a new direction in modern healthcare, which commences an innovative application field of information technology in healthcare industry.

The aim of our paper is to show how federated DWH facilitating EBM can be applied for reliable and secure processing of huge amounts of medical data. Applying evidence-based guidelines (EBG) into the clinical decision making process could improve the quality of health delivery, because it guaranties that only impartial and scientifically verified knowledge will be offered to the physicians. Federated DWH technology enables the acquisition of all available patient data from diverse medical data sources participating the federation, transforms that data and creates the unique patient's electronic health record (EHR). It is not necessary to store the EHR as a single physical entity in a centralized system. Instead, when required, EHR can be aggregated into a single coherent record from data stored in various geographical locations. Moreover the federated approach is a step towards decentralisation of security assurance and is scalable since it is component-based – each new data source can be easily included into the federation, without having to redesign the existing system.

Manuscript received March 30, 2007. This research has been partly funded by the Austrian Federal Ministry for Education, Science and Culture, and the European Social Fund (ESF) under grant 31.963/46-VII/9/2002.

Nevena Stolba is with WIT, Institute of Software Technology and Interactive Systems, Vienna University of Technology, Austria (phone: 4315880118818, fax: 4315880118895; e-mail: stolba@wit.tuwien.ac.at).

Tho Manh Nguyen and A Min Tjoa are with Institute of Software Technology and Interactive Systems, Vienna University of Technology, Austria (e-mail: tho@ifs,tuwien.ac.at, tjoa@ifs.tuwien.ac.at).

Although application of DWH for analytical purposes is just as important as deploying it for operational tasks, we will not handle that subject in this paper, but refer the interested readers to the related work [1].

The contribution of our work is to present a model for building a sustainable clinical decision-support system based on interoperability of heterogeneous medical information systems. These systems are united into a federated DWH, considering widely adopted international standards for the exchange of healthcare data.

The rest of the paper is organized as follows: we introduce the concept of federated DWH as well as the sense and response mechanism. Than, a scenario, which involves previous discussed components, is given. We finalise the paper with related work in the area and a conclusion.

II. Federated DWH for Interoperability in Health Care Environment

Most of the patients receive their healthcare from multiple providers. Hospitals, physicians, recovery centres, laboratories, pharmacies and health insurance institutions have their own, isolated patient records. Therefore, they can keep only a fragmental knowledge about the patient's health condition.

Due to the high confidentiality of healthcare data and the privacy policy of participating organisations, we propose a collaborative system (federated DWH) instead of an integrated system approach (physical DWH) for joining of distributed data assets. Rather than duplicating the sensitive data into a centralized DSS, a federated DWH virtually ties together network providers so that fundamental operational, analytical and research activities can be efficiently realized.

In our model (Fig.1) the different medical treatment domains, the social insurance domain, the pharmaceutical domain and the EBG repository participate in one federation. Some of them communicate with the federation via web services; others may transfer their sensitive data directly to the federation, in case of a federated query. Since only a unique interpretation of the joined data should exist, it is necessary to have a unique common federated schema. As shown in Fig. 1, the essential part of the model is the *ontological integration layer*. Wrappers and mediators [1], [2] are the main architectural components of a mediated query system. Participating organisations use internationally adopted standard message formats for transmission of their health information to the federation. Such standards (e.g. HL7 [3], ENV 13606, openEHR) set the structure and data types required for seamless integration between the systems.

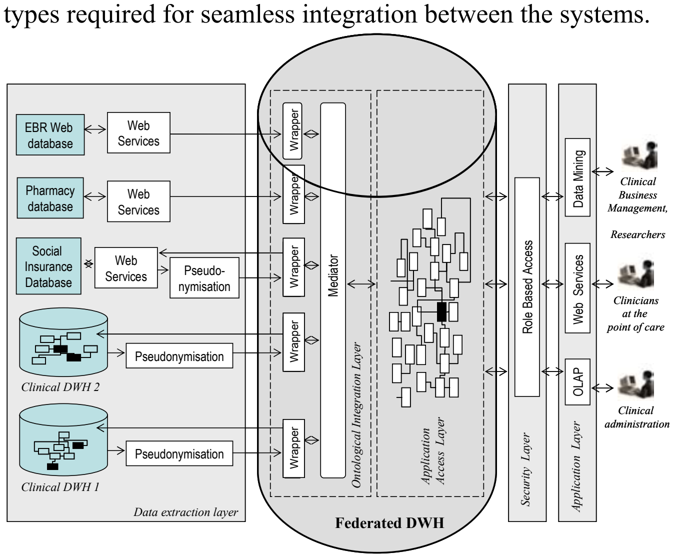

Fig.1: Medical Federated DWH

Fig. 2 represents an extract of the logical data model of our federated DWH. This example incorporates patient personal data, medical history, health insurance data as well as EBG. By querying the clinical DWH when examining the patient, the clinician gets a concise and aggregated overview of patient's health condition. We can take advantage of DWH OLAP-tool functionalities and drill down into detailed representation of previous diagnoses, prescribed treatments and drugs.

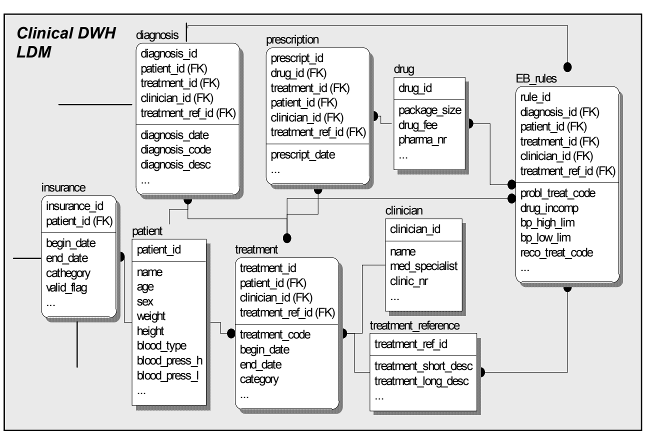

Fig. 2: Part of a clinical DWH LDM

III. Sense and Response Mechanism in Healthcare

The Sense & Response mechanism [4] was initially developed to help organizations to monitor the IT events in business processes in order to proactively respond to business situations or exceptions with minimal latency. The data processing is controlled by the *Sense & Response loops* which is able to continuously receive, process and augment events from various source systems, and to transform these events near real-time into performance indicators and intelligent business actions.

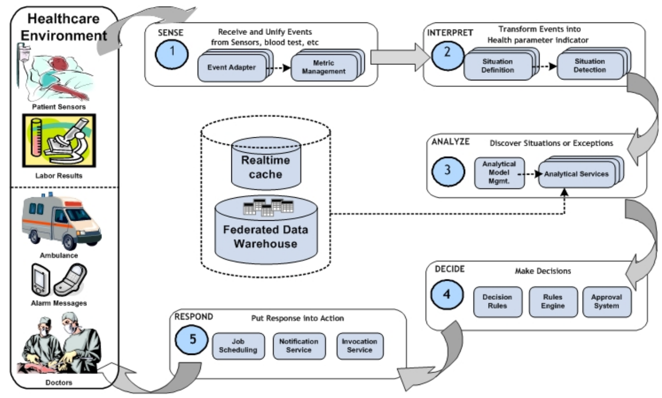

Fig. 3: Sense & Response in healthcare scenario

In this paper, we apply the *Sense & Response mechanism* in healthcare systems with the aim of real-time monitoring the heath condition of the high-risk patients to instantly react in the emergency case. The *Sense & Response loops* contain 5 stages as described in Fig. 3. In the *sense stage*, events (i.e. sensors data from the patients, blood examination results etc) are continuously captured and transmitted into a unified format. The *interpret stage* transforms the raw event data into the heath care indicator (such as heart vibration, percentage of oxygen in bloods and so on). In the a*nalyse stage*, the heath information will be analyzed to determine the root cause and predict the next states. This progress acquires the historical data from the federated DWH to analytically conduct a pattern. Depending on the analytical result, the *decide stage* proposes the best option for improving the current patient's health situations and determines the most appropriate action for a response to the situation. Finally, the real actions (i.e. a call to the doctor or ambulance, sending an alarm or messages, etc) are conducted in the *response stage*.

IV. Real-World Scenario: DWH Application in Real-Time Sense and Response Environment for Support of Emergency Room Decision-Making

Recent advances in the treatment of acute coronary syndromes has raised awareness that prompt presentation for chest pain may be life saving. Most patients presenting with chest discomfort have a non-ischaemic electrocardiogram (ECG) on presentation, but are routinely admitted to hospital because of diagnostic uncertainty for occult myocardial infarction (MI) or ischaemia [5]. We will show how the federated DWH facilitating EBG and integrating newly developed device for non-invasive detection of ischaemia can support decision-making process at the point of care, to rule out the heart attack.

The decision to discharge patients with chest pain from non-cardiac origin from the emergency room (ER) is a challenging task. There are many uncertainties and legal aspects, which makes the decision difficult. One of the problems with chest pain patients presenting to ER is that diagnosis is deferred for at least 6 hours when the enzymatic markers become diagnostic. An early immediate diagnosis of chest pain of non-cardiac origin may be of great help for the clinician to avoid unnecessary admissions: Gorenberg et al. describe in [5] their new non-invasive device for measurement of central aortic pressure changes. The ascending limb of the aortic pressure (dP/dtejc) was measured with a newly designed computer controlled device. All patients with dP/dtejc ≥150 were discharged after at least 1 day of admission and MI was not identified in any patient. Using this criterion, nearly 40% of patients presenting with acute chest pain could be spared the risks and costs of unnecessary admission to hospital and more invasive cardiac testing.

provides the clinician with powerful but easy-to-use tools for quick decision making.

At the admission into the ER, the device described above will be applied first. This examination takes only 10 minutes and it can be used for first quick exclusion test. According to [5], patients with dP/dt_{ejc} <150 presumably had suffered a heart attack and will be hospitalized for further examinations. For all other patients, their medical history needs to be checked, before they can be discharged. Here, DWH will be checked for the first time: The Sense & Response Loop 1 queries the federated DWH to verify if the particular patient has suffered from MI, severe arrhythmias or severe hypotension before. Patients, whose EHR contains such entries are susceptible to heart attack and will also be hospitalized for more detailed observations.

In order to create EHR for the particular patient, the medical history data is gathered into the federated DWH from all available sources (point 2 in Fig. 4).

Hospitalized patients consequently undergo more detailed examinations like electrocardiogram (ECG), exercise ECG, blood test and in some cases even myocardial scintigraphy or chest and heart X-ray. The results of these examinations are input parameters for the second Sense & Response Loop.

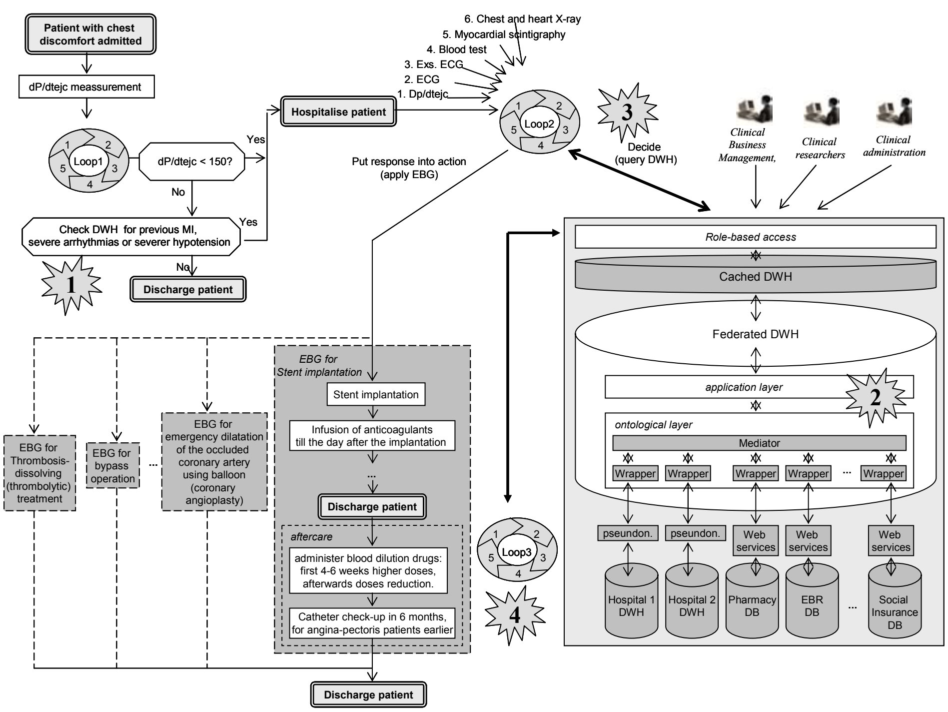

Fig. 4: Decision making process for chest-pain patients

However, this method has limitations concerning the patients with previous MI and severe arrhythmias and patients with severe hypotension. The patient's EHR thus needs to be checked every time the observation is carried out, in order to prevent erroneous diagnoses. A DWH, which is integrated into the whole observation procedure, offers detailed insight into patient's medical history and

At this point (Fig. 4, point 3) EHR (old data) is merged with the examination findings (new data). The result data is used as input for finding the best fitting treatment for a given patient and a given disease.

The statistical excellence of DWH can be fully exploited in this stage. Predefined analytical procedures automatically search through the EBG database, drill-down and roll-up as well as slice and dice functions are deployed in order to detect the most effective treatments. Usually, more than one treatment is offered to the physician in charge. In our scenario, these are bypass operation, coronary angioplasty, stent implementation, thrombolytic treatment etc. At this stage, physician has to interact with the system in order to decide which treatment will be the best one to apply.

In the next step, the chosen treatment (stent implementation) is applied. According to the selected EBG, the patient will receive the anticoagulants intravenous till the day after the implementation. After that, diverse tests are made before the patient can be released from hospital.

According to the EBG, in the first 4-6 weeks patient receives higher doses of blood dilution drugs. Afterwards, the dose is reduced.

During the aftercare time, DWH is deployed for checking of recovery process (Fig. 4, point 4). Especially health condition of the high-risk patients is regularly checked against the available experience (history) values stored inside the federated DWH (Sense & Response Loop 3). With the support of huge volumes of historical data residing in the DWH and powerful statistical tools available, an alert is automatically issued whenever a deviation of recovery data is noticed.

V. Related Work

As stated in [6], improving "Management of Health Risks" and Patient Safety is one of the cornerstones to assure policy support for the European Commission FP7 eHealth research topics. Emergency response systems are one of the significant factors of safety healthcare management. There are thus several proposed prototypes and developed projects on the topic. Authors in [7] propose a scalable emergency medical response system that couples the efficient data collection of sensor networks with the flexibility and interoperability of a web services architecture. [8] present a wireless medical monitoring system which is capable of receiving and processing the pulse-oximetry signals from one ore several monitored patients. SAPHIRE [9] is an Intelligent Healthcare Monitoring for the Homecare Scenario using multi-service architecture. Akogrimo E-Health [10] deployed Heart Monitoring and Emergency Scenario on the Mobile Grids. CodeBlue [11] proposes a wireless infrastructure intended for deployment in emergency medical care, integrating low-power, wireless vital sign sensors, PDAs, and PC-class systems.

In general, the existing approaches focus on the protocols of data collection from sensor network and the communication between components to process data, mostly using agent technology, and to deploy the presentation data in mobility devices. These approaches thus could not deal with ad-hoc analysis to recognize the pattern-based data trends. With the use of federated DWH combined with the Sense & Response loop, our approach could process the ad-hoc query in the acceptable response time.

VI. Conclusion

Interoperability between medical IS is necessary for building sustainable healthcare decision-support systems. Federated DWH has been increasingly proposed as an alternative to conventional centralised approaches, with a high transformative potential role within healthcare structures. Although the relevance and use of federated DWH within the healthcare domain is obvious, there are still many technical and organizational open issues. In this paper we showed, that a federated clinical DWH that facilitates EBM is a reliable and powerful platform for production and dissemination of clinical knowledge. Our universal, simple and flexible common conceptual model enables potential future integrations of other healthcare organisations to be done seamlessly and with a minimum effort.

References

[1] Stolba N, Nguyen M. and Tjoa A M. Towards a DWH Based Approach to Support Healthcare Knowledge Development and Sharing, submitted for the publication at 2007 IRMA Int. Conference, Vancouver, Canada, May 2007.

[2] Beneventano D, Bergamaschi S, Guerra F and Vincini M. Synthesizing an Integrated Ontology, IEEE Internet Computing Magazine, September-October 2003, 42-51.

[3] Heitmann KU. Kommunikation mit HL7 Version 3 – Aspekte der Interoperabilität im Gesundheitswesen, Datenbank Spektrum, 17/2006, dpunkt.verlag, pp. 12-16.

[4] Nguyen M., Tjoa AM and Schiefer J. SARESA: An Approach Towards a Real-time Business Intelligence Solution and Its Use for a Fraud Detection Application, 8th ACM Int. Workshop on DWH and OLAP (DOLAP 05), pp.77-86.

[5] Gorenberg M, Marmor A and Rotstein H. Detection of chest pain of non-cardiac origin at the emergency room by a new non-invasive device avoiding unnecessary admission to hospital, *Emerg Med J* 2005; *22*:486-489, BMJ Publishing Group Ltd, and British Association for Accident and Emergency Medicine.

[6] eHealth 2006 Workshop. http://www.ehealth-for-safety.org/workshops/bio_medical%202006/bio_medical_index.html

[7] Hashmi N, Myung D, Gaynor M and MoultonS. A Sensor-based,Web Service-enabled, Emergency Medical Response System, EESR '05: Workshop on End-to-End, Sense-and-Respond Systems, Applications, and Services.

[8] Morón J, Casilari E, Luque1 R, Gázquez A: Wireless Monitoring System for Pulse-oximetry Sensors, Proceedings of the 2005 Systems Communications (ICW'05).

[9] Hein A, Nee O, Willemsen D, Scheffold T, Dogac A, Laleci G. SAPHIRE - Intelligent Healthcare Monitoring based on Semantic Interoperability Platform - The Homecare Scenario ,1st European Conference on eHealth (ECEH'06).

[10] Loos C. E-Health with Mobile Grids: The Akogrimo Heart Monitoring and Emergency Scenario, Akogrimo White Paper.

[11] D. Malan, T. Jones, M. Welsh, S. Moulton: CodeBlue: An Ad Hoc Sensor Network Infrastructure for Emergency Medical Care, International Workshop on Wearable and Implantable Body Sensor Networks, BSN 04.

[12] D.L. Sackett, W.M.C. Rosenberg, J.A.M. Gray, R.B. Haynes, W.S. Richardson, "Evidence-Based Medicine: what it is and what it isn't". *British Medical Journal (BMJ)*, Vol. 312 (7032), 1996, pp. 71-72.