Capture and Reuse of Knowledge in ICT-based Decisional Environments

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Health care practitioners continually confront with a wide range of challenges, seeking to making difficult diagnoses, avoiding errors, ensuring highest quality, maximizing efficacy and reducing costs. Information technology has the potential to reduce clinical errors and to improve the decision making in the clinical milieu. This paper presents a pilot development of a clinical decision support systems (CDSS) entitled MEDIS that was designed to incorporate knowledge from heterogeneous environments with the purpose of increasing the efficiency and the quality of the decision making process, and reducing costs based on advances of information technologies, especially under the impact of the transition towards the mobile space. The system aims to capture and reuse knowledge in order to provide real-time access to clinical knowledge for a variety of users, including medical personnel, patients, teachers and students.

Keywords*: Clinical Decision Support Systems, Knowledge Management, Knowledge Interoperability, Mobile Interface, Object-relational Mapping*

1 Introduction

Clinical decision support systems (CDSS) are computer systems designed to impact clinician decision making about individual patients at the specific point in time when these decisions are made [1]. With the increased focus on the prevention of medical errors, CDSS have the potential to change the way medicine has been taught and practiced. CDSS have been shown to improve both patient outcomes, as well as the cost of care.

There are a variety of systems that can potentially support clinical decisions and decision support systems have been incorporated in health-care information systems for a long time, but usually these systems have supported retrospective analyses of financial and administrative data [2] [3]. They provide support for financial decisions, but they do not facilitate knowledge acquisition and reuse.

In the recent years, complex data mining approaches have been proposed for similar retrospective analyses of both administrative and clinical data. These retrospective approaches can be used to develop guidelines, critical pathways or protocols to guide decision making at the point of care, but they are not considered to be CDSS. This distinction is important because it allows users to understand that even if a system is categorized to include decision support capabilities, they might be retrospective type systems that were not designed to assist clinicians at the point of care.

The main characteristics that differentiate CDSS refer to the *timing* at which they provide support (before, during, or after the clinical decision is made) and how *active* or *passive* the support is, respectively whether the CDSS can actively provide alerts or passively responds to physician input or patient-specific information.

CDSS also vary in terms of how easy a busy clinician can access it or whether the information provided is general or specialty-based. In this perspective, technology acceptance models need to be considered. There is also a tendency to incorporate CDSS in computer-based patient records and physician order entry systems.

Another categorization scheme for CDSS is whether they are knowledge-based systems, or non-knowledge-based systems that employ machine learning and other statistical pattern recognition approaches.

2 Knowledge-based Clinical Decision Support Systems

Organizations are no longer valued solely for what they have done – but the potential of what they might be able to do. This, organizational managers will be valued for their ability to leverage knowledge to make unparallel advances in their organization's ability to innovate, compete and connect with the actors of the environment they activate in so that they can collaborate in decision-making [4] [5]. The promise and interest in knowledge management is not in knowing, but in being able to act creatively based on what you know and you are able to access. Innovation results from knowledge that it why it is important to consider the infrastructure behind knowledge management. The raw goods of intellectual property – experience and know-how – must be channeled and made available; otherwise innovation can be hampered [6]. This is a very real problem for many organizations.

Many knowledge-based CDSS were developed within expert systems research [5] [7], as medicine was considered a good domain in which these concepts could be applied. The developers of these systems aimed to adapt them in order to use them more easily to support real-life patient care processes. Some of them were diagnostic decision support systems that did not intend just to simulate expert decision making, but to assist the clinicians in their own decision making process. The system did not provide the answer to a problem, but aimed to provide information for the user. It was the user that had to filter the information and to exclude erroneous or useless information. The user played an active role and he was not just a passive recipient of the output the system provided. This focus on the interaction of the user with the system and also with other users of the system is very important in order to set appropriate expectations for the way the system will be used.

CDSS comprise three main components:

- the knowledge base;
- the inference engine;
- a mechanism to communicate with the user.

The knowledge base contains compiled information that, most of the times, is in the form of *if-then* rules. For example, IF a new order is made for a particular blood test that tends to change very slowly, AND IF that blood test was ordered within the previous 48 hours, THEN alert the physician [9]. This rule is designed to prevent duplicate test ordering.

The inference engine contains the formulas for combining the rules or associations in the knowledge base with actual patient data.

The communication mechanism represents a way of entering patient data into the system and getting the output of the system to the user that has the role of the decision maker. Based on previous developments, CDSS can incorporate data that were already entered in electronic form. Outputs to the clinicians can consist of recommendations or alerts.

CDSS can be developed to assist a variety of decisions. For example, diagnostic decision support systems can provide a list of potential diagnoses, based on the patient's signs and symptoms. The knowledge base of the decision support system contains information about diseases and their signs and symptoms. The inference engine maps the patient signs and symptoms and can provide suggestions for diagnoses that can help the clinician to better his decisions. In most cases, the system generates alternatives, and the clinician will eliminate some of the choices, based on his experience and because he usually knows more about a patient that the system [10].

Other systems can provide support for medication orders, which represent a significant cause of medical errors. For example, the patient's laboratory test results for the blood level of a prescribed medication can constitute the input for the system. The knowledge base might contain values for therapeutic and toxic blood concentrations of the medication and rules on what should be done when a toxic level of the medication is reached. If the medication level is too high, the system can send an alert to the physician and he can react accordingly.

Health care practitioners continually confront a wide range of challenges, seeking to make difficult diagnoses, avoid errors, ensure highest quality, maximize efficacy and reduce costs. Patients and the public have many questions and needs in evaluating their health and the decision making process also requires help. The array of choices and the many factors that affect a decision are more complex and require detailed knowledge.

Advances of information technologies provide the necessary background for the overcoming these obstacles, yet the prospect of using computers in decision support systems has turned to be a much harder problem than has initially been appreciated. Even the simple forms of decision support require large scale efforts to go from an initial implementation that aimed to show the effectiveness of the system in particular application settings to having the ability to provide ongoing management of decision support in the same settings. It is also necessary to move from that capability to wider development beyond a single application, within the same or different institutions. This becomes a greater problem when the aim expands to include regional or national adoption of the system, even for limited aspects of health, such as appropriate utilization of imaging procedures.

Challenges that are manageable with some effort in a single environment become much more difficult in a multi-institutional setting [3]. They relate to maintenance and update of the knowledge underlying decision support; managing the corpus of knowledge, in terms of conflicts, overlaps and gaps; establishing the best ways to deploy various forms of decision support [4] [7], in terms of their integration with practice and impact on efficiency and workflow; and disseminating knowledge that has been well established so that it can be reused in multiple sites, making such knowledge platform-independent. Addressing this last challenge is essential to leveraging knowledge and making the financial effort worth on a broad scale.

3 The main features of the MEDIS system

MEDIS is a clinical decision support system that has been developed as a pilot project in order to explore the potential of computer assisted decision making in clinical environments.

MEDIS addresses the new challenges brought forth by the need to provide real-time feedback to decision makers, and it has been designed to provide multi-dimensional assistance to various categories of users, such as medical personnel, patients, teacher or students.

The main ***objectives of the knowledge-based CDSS*** comprise the following:

- *to make knowledge easier to capture and reuse*:
  - by facilitating real-time, structured access to information and knowledge, in desktop and mobile environments, regarding patients, diseases and treatments, anytime and anywhere, the decision-making process benefits of an overall improvement;
- *to foster optimal problem-solving, decision-making and action by its users, in regard to*:
  - treatment options for clinical problems, customized for each patient, assisting medical personnel in taking the best decision; the system signal incompatibilities between the patient record and the prescribed treatment, reducing the number of medical errors;
  - learning activities carried out within medical educational institutes; teacher and students can access the knowledge database and they can use it during the learning process to obtain sustainable qualifications;
  - secured access to clinical data for patients; each patient can access his own records and the physician's recommendations.

The primary task of the system is to select knowledge that is pertinent and/ or to process data to create the pertinent knowledge. This feature is improved as the system can make the selection based on patient-specific data. This increases the relevance of the system to the individual patient. The selection of knowledge and processing of data involve inferencing processes, algorithms, rules or association methods. The main results of the system are to perform some actions, and usually they refer to making recommendations.

Potential users:

The user of the clinical decision support system include physicians, nurses, laboratory technicians, pharmacists, patients, teachers, students or other individuals that are interested in accessing medical information. In some cases, the user may be another software application. The setting are various and they can refer to problems that arose in clinical practice, a health maintenance/ prevention care question of a patient, or a training/ educational exercise.

Components

a. authorization

The system provides three different types of access based on:

- *a private section with full rights* that addresses the medical personnel, which benefit of access customized by competency area. For example, a physician can access only the data of his patients.
- *a private section with restricted rights* that can be used by patients, companies and other institutions to access own data or by teachers and students in practice-based learning environments. The system provides confidentiality of patient data as follows: The data base can be accessed only by obtaining a username and a password. The patient can access only their personal data, while the learning actors can access exclusively information regarding diagnoses, treatments, receipts, etc.
- *a public section* that present general information and medical news, which can be accessed directly through the web application.

Fig. 1. Authorization in the system

b. The system provides extensive data management:

- *patient management* that comprises the full history of a patient, including treatments, diseases, contraindications, restrictions, recommendations, etc (figure. 2);
- *diseases management* that contains detailed information, recommendations, knowledge and reasoning, which can be accessed through advanced search options based on symptoms;
- *medicine management* that support users in improving their decision making process as the data base stores information on medication and the incompatibilities between them and certain diseases (figure 3);
- *treatment management* based on which the system send automatic alerts to the physician in case it identifies incompatibilities between the prescription, the history of the patient's treatments and the prescribed medication (figure 4);
- *prescription management* associated with patient visits to the physician, with allows the latter to synchronize the previously

prescribed treatments with the patient evolution.

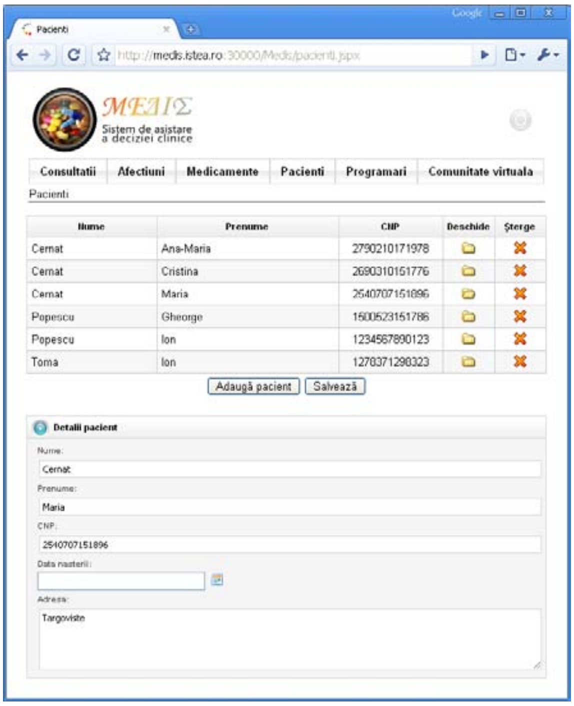

Fig. 2. Patient management

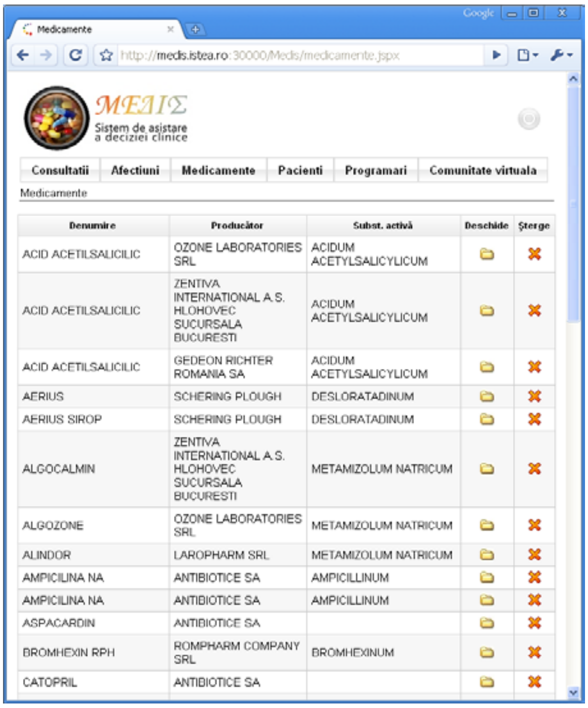

Fig. 3. Medicine management

c. search functions

MEDIS collects knowledge generated in heterogeneous environments. The database backend is based on Hibernate, thus the system can incorporate both relational and object-oriented data bases, increasing accessibility and lowering costs for knowledge acquisition. As gathering knowledge does not reach its maximum efficiency unless it is paired with powerful search options, MEDIS combines the two components with the purpose of enriching users' experience when interacting with the system.

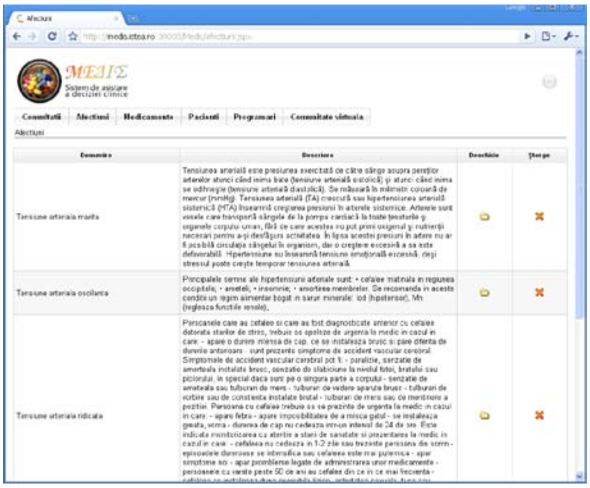

Fig. 4. Treatment management

One of the most important functionality of the systems refers to its search options (figure 5) that facilitate easy access to information and knowledge and can provide real-time support for the system's users.

- *Simple*: by word or phrases;
- *Advanced*: by multiple words, using the *or* and *no* operators.

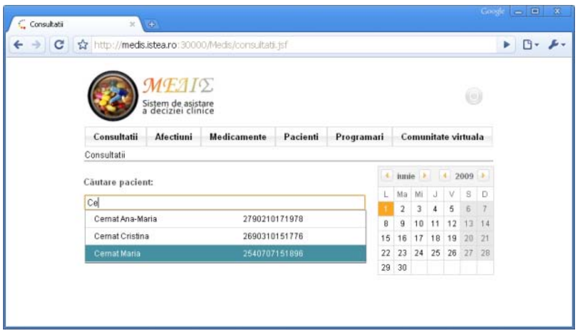

Fig. 5. Search options

d. comment options

The system provides comment options as aims to capture timely contextual generated knowledge and facilitate its reuse, by promoting a permanently updated set of knowledge that support clinical decision making.

The comments can be private or public.

e. statistical functions

The system facilitates data extraction and syntheses, generating statistics and charts by predefined and customized criteria, which allows managers, administrators and users to evaluate the system.

f. mobile graphical user interface

The system can be accessed on handheld devices, such as PDAs, XDAs, smart phones, iPhones. This increases accessibility and provides support for decision making in ambulatory environments. Thus, the system provides real-time assistance anytime, anywhere and constitutes an innovative approach to CDSS [11] based on the use of advances in mobile technologies.

In order to facilitate quick access for interventions in ambulatory circumstances, the system allows access directly to the patient's medical records by scanning a two dimensional barcode printed on the patient's health card.

Because the patient's medical records contain sensitive information, the link contained in the 2D bar code can only be accessed by users who have already been authenticated in the system as users with full access rights.

As the number of Internet connections and especially of wireless connections increases rapidly, such a development takes benefits of the latest access technologies.

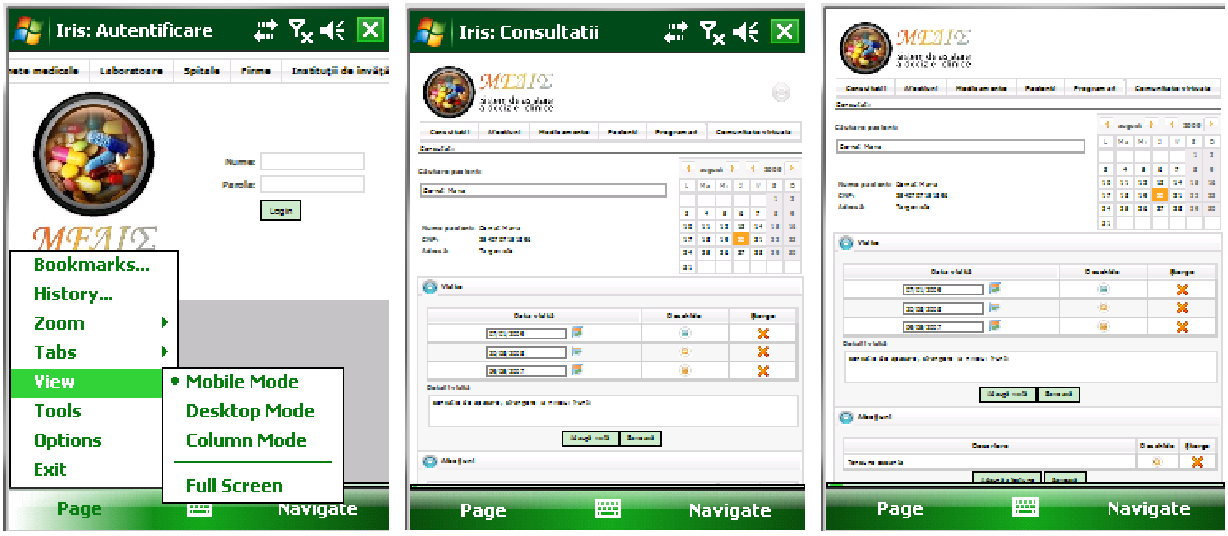

Fig. 6. Mobile interface

4 Delivering web content to mobile devices

Given the same URL (Fig.6) used to access our web application, one can easily observe the difference between:

- Mobile browser configured in mobile view mode;
- Mobile browser configured in desktop view mode;
- Mobile browser configured in one column mobile view mode with full screen.

Designing applications or web sites for mobile phones remains a challenge and the development of mobile application has to consider certain standards and recommendations [12].

When Web pages are specially designed for desktop capabilities, in term of size displays and browsing software, if they are accessed on a mobile device these results in a poor or unusable experience, as pages are not laid out as intended [13]. Because of the limited screen size and the limited amount of material that is visible to the user, context and overview are lost and the page usually requires considerable scrolling to be visible, especially if the top of the page is occupied by images and navigation links. In these cases the user gets no immediate feedback as to whether their retrieval has resulted in the right content. It is particularly important in the mobile context to help the users create a mental image of the site, by adopting a con-

sistent style that can be considerably diminished by an uneven style.
Delivery of content to mobile devices requires solid customization in the attempt to encourage users to become mobile. The developers of the MEDIS system have considered the following recommendations:

- *Maintain thematic experience for content accessed from different devices:* content should be kept similar, no matter if it is accessed from desktop or mobile devices, so that users can access it easily and feels comfortable in the mobile virtual space.
- *Exploit device capabilities for an enhanced user experience*: mobile devices provide different functions, based on the market share they target; these functions should be exploited to a maximum in order to provide an enriched experience for the mobile user and encourage the user to assimilate mobile technologies. Thus, developers should adopt an adaptive design by detecting device characteristics and tweaking the user interface. By adapting the system and/or the content to support specific functions of a device or group of devices, the users obtain better experiences.
- *Provide solutions for deficient implementations:* This refers to differences in interpretation between browsers and also deficiencies in implementation caused by non-support of mandatory features. The system should be able to adapt itself in case it encounters clients that do not respect defined standards, or lack part of the standard implementation. Most of the time, there are workarounds that can be used in order to obtain the same result as in standard browsers.
- *Test on actual devices:* because of the vast number of models and of differences between mobile devices presents on the market today, it is best to test the website on as many different phone models as possible, in order to obtain a sustainable system development. Sometimes the browser implementation can differ greatly for the same phone model, depending of the firmware version installed.
- *Keep the URIs of site entry points short:* The web site should be designed with quick URIs that can take the user to a specific page based on the content ID. For example, the user can access the address http://news.mobi/45123 and be automatically taken to the article with ID 45123.
- *Provide minimal navigation at the top of the page:* The navigation menu should be designed to occupy little space; at the same time designers should provide links to the most important pages. It is probably best if content is structured hierarchically to provide the content hierarchy leading to the current page.
- *Provide a balance structure:* mobile application designers should not include a large number of links at the top of the mobile web site; users are encouraged to become mobile when they need to access as much content as possible, as quickly as possible.
- *Provide consistent navigation mechanisms*: designers should preserve the same navigation mechanism across a service to allow users to identify them easier and feel comfortable with the mobile environment.
- *Assign access keys to links in navigational menus and frequently accessed functionality*: easy access is a top priority in the mobile world; users would enjoy the mobile experience, if they can access information with just ‘a single click’.
- *Avoid pop-ups*: pop-ups or other informative windows can affect the quality of the interaction, reducing the attractiveness of the web site.
- *Use of clear and simple language*. Users in a mobile environment expect specific and accurate pieces of information or knowledge, rather than browsing. They usually access mobile knowledge when they really would like to find specific information, at a specific moment, maybe even for an urgent matter. Extensive reading will discourage the user and make them give up on the experience. Audio options can be provided for extensive texts.

- *Provide correspondence between size of page and device capabilities*: the reduced memory of mobile devices can limit access to content from a various range of mobile devices.
- *One direction scrolling*: Users can improve the comprehension of a text and eagerness to use mobile browsers, if they don't have to scroll in all directions and loose coherence.
- *Avoid large or high resolution images:* As mobile devices present limited storage capacity, images should be resized at the server, to avoid unwelcomed experiences
- *Avoid using tables or frames:* Due to screen limitation, tables and frames rarely fit. To avoid incomprehensible display, it is better to avoid tables that contain many rows and columns, or frames; otherwise the information cannot be accesses properly.
- *Error handling*: when errors occur, users need to be able to understand what has happened and also how they deal with the problem; otherwise they might get reluctant and give up on the experience.
- *Avoid free text entry and provide preselected default values:* To compensate the reduced size of most mobile devices, users need to be able to use access keys for an easier navigation in a mobile browser. Also, in designing for small devices, speech input is a viable alternative for devices too small for extra buttons.

The design and the development of MEDIS for the mobile world has required sound adaptation to the basic environmental conditions that restrict wide usage, in order to provide enriched user experience.

5 Secure mobile World Wide Web connection

At the core of every web application is the fact that all of its functionalities are communicated using Hypertext Transfer Protocol (HTTP), and its results are typically formatted in HyperText Markup Language (HTML). The only difference between HTTP and Hypertext Transfer Protocol Secure (HTTPS) is that an HTTPS connection has extra setup at the beginning. It negotiates a secure channel, and then it sends normal HTTP over that channel (11, 15).

Security objectives in general terms fall into one or more of the following objectives:

- *access control*: to assure that the person or the computer at the other end of the session is permitted to do what he/ it asks for;
- *authentication*: to assure that the resource (human or machine) at the other end of the session really is what it claims to be;
- *integrity*: to assure that the information that arrives is the same as when it was sent;
- *accountability*: to assure that any transaction that takes place can subsequently be proved to have taken place. Both the sender and the receiver agree that the exchange took place (also called non-repudiation);
- *privacy*: to assure that sensitive information is not visible, usually carried out by encryption.

The security objectives remained the same along years, but their environment has expanded with the advanced of technology to more complex circumstances and interactions, bringing forth new challenges. Today, users expect to be able to access data securely no matter where they are and remote connections require extra qualifications. Although, in recent years, in terms of Internet access the developments of the mobile technologies have begun to fill the gap between mobile devices and the desktop computers, there are still many differences between how content is rendered in mobile web browsers and on desktop computers due to hardware, software and physical device constraints. With this in mind, the best way to create a friendly web experience for the mobile users is to create customized context, specially adapted to the device specifications.

Mobile content developers have to take into account the wide variety of mobile browsers and operating systems that are available on the market today. While high-end devices with operating systems such as iPhone OS, Windows Mobile, Android, and Symbian are better equipped to handle Rich Internet Applications (RIA), they only comprise a small number of the mobile device market mostly due to the high costs of such devices. In order to make the make the content accessible to as many users as possible, designers of mobile web applications need to maintain a delicate balance between the features that they provide to end users and the features that they require from the device.

In order to access data using a mobile web interface, the developers have used an *encryption data connection*. In this way, no third party is able to intercept the communication between the client and the server. HTTPS is a protocol that encrypts and encapsulates normal HTTP traffic using SSL (Secure Sockets Layer).

Data encryption and client authentication are done through the use of PKI certificates issued to each client and installed in the SIM card of the mobile device. Besides the normal data encryption application, issuing self-owned client certificates allows developers to embed them into the SIM cards and therefore, they can prevent any attempts to copy the private key and allows them to easily revoke client certificates in case a mobile device is stolen or lost.

6 Development technologies

MEDIS was developed using Java. Unlike native applications that access directly the operating systems and the hardware resources, Java applications are executed by a virtual machine (JVM - Java Virtual Machine). Thus, they are isolated from a direct exterior contact and they can access only Java libraries or the functions of the virtual machine [16]. The virtual machine contains the Java Runtime Environment that represents all the standard functions and libraries provided by Java. Java desktop applications (Java SE) are executed directly and function similar to any desktop application, while Java EE Application require an application Server (JBoss) that acts as a Web server (figure 7).

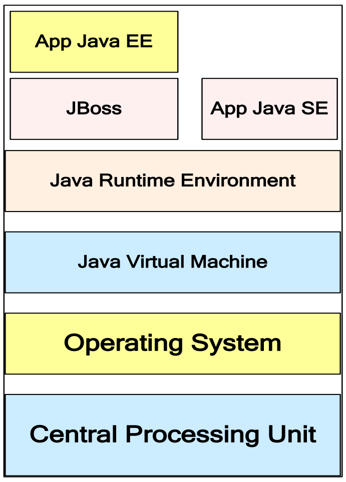

Fig. 7. Development platform for MEDIS

7 Hibernate as a persistence solution

Most significant development projects involve a relational database. The mainstay of most application is the large-scale storage of information [17] [18]. With the advent of World Wide Web, the demand for databases has increased. While the demand for such applications has grown, their creation has not become noticeable simpler. The persistence models suffer to a certain degree from the mismatch between the relational model and the object-oriented model, making database persistence difficult.

Computer-based systems used in clinical environments require a considerable and sustainable amount of storage. More than this, the existing information and knowledge abounds, but they were created in heterogeneous environments, requiring sound interoperability.

The developers of MEDIS have used Hibernate as the database backend because it supports inheritance relationships and various other relationships between classes.

The use of JDBC requires a substantial body of code and careful observation of various rules, such as that governing connection management, to ensure that the application does not leak resources [19].

Hibernate does not require the mapping of one POJO (Plain Old Java Object) to one table, as it allows storage of POJOs in the database. Figure 8 [20] shows how Hibernate fits into the application between the client code and the database.

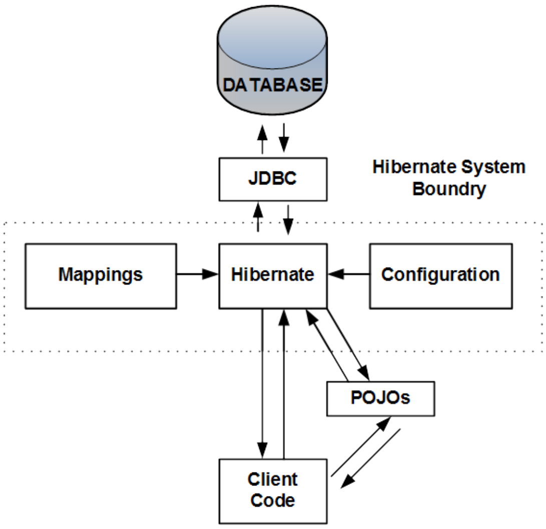

Fig. 8. The role of Hibernate in a Java application

The direct persistence of traditional Java objects is object-relational mapping, which refers to mapping the objects in Java to the relational entities in the database. POJOs can be any Java object at all. Hibernate allows the developers to persist POJOs with few constraints.

The sole condescension to Hibernate is the provision of a private default constructor. Hibernate demands that all POJOs to be stored should provide a default constructor.

A POJO can be constructed out of a selection of table columns, or several POJOs can be persisted into a single table.

Although there is some performance overhead while Hibernate starts up and processes its configuration files, it is generally perceived as being a fast tool. In Hibernate it is possible to specify the mappings at development time [21] [22].

Hibernate persistence has no requirement for a J2EE application server or any other specific environment. It is, therefore, a much more suitable solution for stand-alone applications, client-side application storage, and other environments in which a J2EE server is not immediately available.

Hibernate uses POJOs that can be very easily and naturally generalized for the use in other applications. There is no direct dependency upon the Hibernate libraries, so POJOs can be put to any use that does not require persistence, or they can be persisted using any other "POJO friendly" mechanism [23].

Hibernate presents no problems when handling serializable POJOs.

There is a very large body of pre-existing code. Any Java object capable of being persisted to a database is a candidate for Hibernate persistence [24]. Therefore, Hibernate is a natural replacement for ad hoc solutions, or as the persistence engine for an application that has not yet had database persistence incorporated into it. Furthermore, by choosing Hibernate persistence, developers are not tying themselves to any particular design decisions for the business objects in their application,

One of the benefits often presented for Hibernate is that it is a "thin" solution [25]. Thus, Hibernate does not require an application server to operate. It is therefore applicable in client-side applications.

Also Hibernate makes use of an inordinate number of supportive libraries. If we are to consider the download times and disk space of an applet, Hibernate seems to be something large, but in these days of fast connections and considerable disk space, it is unlikely to be a deciding factor [26] [27].

8 Value-added in the field of CDSS

MEDIS is a system that provides a practice oriented approach to knowledge interoperability and management. The main advantages that the system brings to the decisional environment translate into the following directions:

The system proposes an optimized flow that aims to sustain the relationship between the decision factor and the expert knowledge, by the use of information technologies, in terms of knowledge management and interoperability and real-time access to knowledge. As it is a web-based system, access to knowledge is facilitated anytime, anywhere. The mobile graphical user interface increase access opportunities and expands usage in ambulatory interventions.

MEDIS comprises different dimensions of the decisional process at it addresses both to medical personnel, patients and student activities. This approach provides interconnected benefits for each of the categories. Physicians can capture and reuse the expert knowledge gained by practice, patient can improve their knowledge and can cooperate better when under treatment, as they can obtain enriched domain-specific knowledge, and students can improve their learning process through a direct connection with practice, latest technologies and researches in the domain of clinical interventions.

The system provides a full set of automatic actions that support real-time decision making. The technologies used provide integration of both relational and object-oriented data bases, expanding the acquisition from heterogeneous sources.

The knowledge is validated by practice, as it is generated and assessed by experts in the field. Thus the learning activities are definitely improved.

9 Conclusion

Clinical Decision Support Systems assist decision makers by providing expanded access to relevant information to improve the overall efficiency of the decisional process. MEDIS was developed as a pilot project, and it is based on advanced information technologies that facilitate better clinical decision-making, in desktop and mobile environments [28].

The system brings forth multi-dimensional approaches, addressing to a variety of users and decisional environments, from clinical decision made by physicians to those made by patients or teachers and students. The core of its development is based on capture and reuse of knowledge, as a mean to increase efficiency and to reduce costs.

The design of the system considers the fact that knowledge is generated in heterogeneous environments and knowledge reuse represents a real challenge for the decisional space. In this regard, MEDIS is a system that incorporates technologies, which support the embedment of knowledge accessed from both relational and object-oriented databases. This approach expands the overall efficiency, increases accessibility and reduces the knowledge database development costs.

MEDIS is a web application that allows users to access the knowledge database anytime, anywhere, including in mobile environments with the purpose of providing support also for ambulatory decision-making.

Overall, MEDIS comprises diversity, both in regard to functionalities, development technologies and users. Such integrated approaches sustain the quality and the efficiency of decision systems for long term perspectives.

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