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Emergent Frameworks for Decision Support Systems

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Knowledge is generated and accessed from heterogeneous spaces. The recent advances in information technologies provide enhanced tools for improving the efficiency of knowledge-based decision support systems. The purpose of this paper is to present the frameworks for developing the optimal blend of technologies required in order to better the knowledge acquisition and reuse in large scale decision making environments. The authors present a case study in the field of clinical decision support systems based on emerging technologies. They consider the changes generated by the upraising social technologies and the challenges brought by the interactive knowledge building within vast online communities.
Keywords: *Knowledge Acquisition, CDDSS, 2D Barcodes, Mobile Interface*

1 Introduction

Decision makers are faced with increasingly stressful environments – highly competitive, fast-paced, overloaded with information, data distributed through the organizations, and multinational in scope. Under these circumstances, decision makers expect enhanced tools that can assist them during the decision-making process and that can help them improve their overall performance and skills. Such intelligent information systems should be able to run sophisticated models at the back end, but remain friendly enough at the front end to be used comfortably by any user [1] regardless of the domain s/he operates in.

The combination of the Internet enabling speed and access, the maturation of artificial intelligence techniques [2] and the advances in mobile technologies have led to sophisticated aids to support decision making under risky and uncertain conditions.

This paper explores the development frameworks of decision support systems (DSS), under the impact of emergent technologies, such as bi-dimensional (2D) barcodes and mobile infrastructures. The authors present a computer-based clinical diagnostic tool – MEDIS, a pilot development of a clinical diagnostic decision support system (CDDSS) designed to collect and reuse knowledge form heterogeneous sources, accessible in desktop and mobile environments

The authors analyze the problems encountered in the development, implementation and maintenance of this clinical decision support system and discuss innovative alternatives and solutions. In the paper, the researchers consider the impact of social technologies and provide a new map for navigating through the streams of bytes that leave decision-makers inundated with data, but starved for tools and patterns that give them meaning.

2 DSS Foundation

Along time, researchers and developers have investigated and proposed a vast range of methodologies and techniques to design and develop computerized systems for decision support applications. In general, a *Decision Support System* (DSS) is a computerized information system that assists decision-making activities in various domains such as business, finance, management, manufacturing or medicine [3, 4]. Such DSS can be developed for specific or general-purpose applications, and can be used by individuals or groups.

A DSS gives its users access to a variety of data sources, modeling techniques, and stored domain knowledge via an easy to use graphical user interface (GUI). A useful DSS is able to compile and extract meaningful information from raw data and to suggest potential solutions for users to make informed

decisions. For example, a DSS can use the data residing in databases, prepare a mathematical model using this data, solve and analyze this model using problem-specific methodologies, and can assist the user in the decision-making process through a GUI.
A decision support system can be also defined as a model-based or knowledge-based system intended to support decision making in semi-structured or unstructured situations [4]. A DSS is not meant to replace a decision-maker, but to extend his/her decision making capabilities. It uses data, provides a clear user interface, and can incorporate the decision maker's own insights.
In order to make a computerized DSS useful for practical implementation, it is important to establish several crucial properties that enable the DSS to combine different types of data and information from various sources in a seamlessly manner and without much user intervention [5, 6]. These properties are related to knowledge processing and decision making activities such as knowledge representation, knowledge management and reuse, reasoning and inference techniques, as well as risk analysis.
Based upon the dominant technology component, researchers have identified five generic types of DSS: communication-driven, data-driven, document-driven, model-driven and knowledge-driven [7]. The enabling technology of a DSS can be a mainframe computer, a client/ server LAN, a spread sheet, or a web-based architecture [8, 9].
Some of the major DSS capabilities are the following [1]:

- To cumulate human judgment and computerized information for semi-structured decision situations. Such problems cannot be conveniently solved by standard quantitative techniques or computerized systems;
- To promote a design that is easy to use. User friendliness, graphical capabilities, and attractive human-machine interface increases the effectiveness of a DSS.
- To use models for analyzing decision-making situations, sometimes based on a knowledge component;
- To improve the effectiveness of decision making rather than its efficiency;
- To provide support for individuals as well as for groups.

A DSS application contains five components: database, model base, knowledge base, GUI and user (Fig. 1). The database stores the data, model and knowledge bases store the collections of models and knowledge, and the GUI allows the user to interact with the database, model base, and knowledge base.

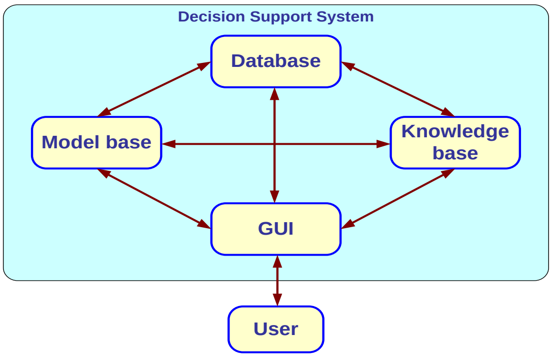

Fig. 1. Main components of a DSS

The database and knowledge base can be found in a basic information system. The knowledge base may contain simple search results for analyzing the data in the database. For example, the knowledge base may contain how many employees in an organization's database have worked within the organization for over ten years.
A decision support system is an intelligent information system because of the addition of the model base. The model base has the models used to perform optimization, simulation, or other algorithms for advanced calculations and analysis. These models allow the decision support system to not only supply information to the user but aid the user in making a decision.

3 Clinical Diagnostic Decision Support Systems

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 sup-

port 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 Clinical Decision Support Systems (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.
Past and present CDDSS (Clinical Diagnostic Decision Support System) incorporate various models of the exceptionally complex process of clinical diagnosis (11).
The process of diagnosis entails a sequence of interdependent, often highly individualized, tasks:

- evoking from the patient's initial history and physical examination findings;
- integration of the data into plausible scenarios regarding known disease processes;
- evaluating and refining diagnostic hypotheses through selective elicitation of additional patient information, such as laboratory tests or serial examinations;
- initiating therapy at appropriate points in time (including before a diagnosis is established); and
- evaluating the effect of both the illness and the therapy on the patient over time.

Diagnosis is a process composed of individual steps. These steps go from a point of origin (a question and a set of presenting findings and previously established diagnoses), to a point of destination (an answer, usually consisting of a set of new established diagnoses and/ or unresolved differential diagnoses).
While the beginning and end points may be identical, the steps one diagnostician follows may be very different from those taken by another diagnostician and the same diagnostician may take different steps in two nearly identical cases.
Because expertise varies among clinicians, different individuals will encounter different diagnostic problems in evaluating the same patient. For instance, they may generate dissimilar questions based on difficulties with disparate steps in the diagnostic process, even if they follow exactly the same steps.

4 Challenges and Needs in CDSS Development

Healthcare is probably one of the most complex business models given the uniqueness of the marketplaces in which it operates. The nature of the services required corresponds to a variety of ailments that are attributed to vast numbers of patient – factors that add to the moss of issues to manage.
Complexities for health-care organizations are heightened when considering the numerous data exchanges that are involved with services provided to patients.
Data exchange can be plagued by myriads formats, captured, and stored in a variety of repositories. These exchanges introduce further complexities in the form of "vocabulary", or in other words, the coding languages that are required to identify types of services that vary considerably from payer to payer, from state to state, and service type to service type.

Also, data in general come from a multitude of different "niche" systems and are presented in many different ways (e.g., text reports, spreadsheet, etc.) and need to be integrated and presented to a caregiver or analyst in a consistent and coherent manner. It is the combination of all these factors that begin to describe the underpinnings of the spectrum of healthcare informatics.

Data provide the building blocks to information and knowledge, vital resources to administrators, practitioners, and decision makers in healthcare organizations. The process of transforming data into information is a daunting task, and given the complexities described above, the task is particularly challenging in this unique industry.

A large number of computer-based clinical decision support systems have been developed and their usefulness evaluated over the past 40+ years [12].

These systems have involved various types of decision support like recognizing that a laboratory test result is out of a normal range, or that a medication being ordered has a dangerous interaction with another one that a patient is taking, or determining that a patient is now due for a flue shot. They have progressed on more complex forms of decision support such as that involved in constructing a differential diagnosis or selecting an optimal treatment strategy. They have proved their success in reducing errors, reducing costs and providing a variety of other benefits.

Despite all the promise and eager anticipation, the prospect of using computers in decision support has turned out to be a much harder problem than generally is appreciated [11, 12].

Even for the simplest forms of decision support, it takes a large scale-up of effort to go from an initial implementation, aimed at showing that clinical decision support is effective in a particular application setting, to having the ability to provide ongoing management of decision support in the same setting.

A further leap is required to move from that capability to wider deployment beyond a single application, even within a single institution. This becomes a bigger issue if the goal expands as to address the possibilities of regional or national adoption of accepted clinical practices and guidelines.

Challenges that are manageable with some effort in a single environment become much more difficult in a multi-institutional setting. These relate to maintenance and upgrading of the knowledge underlying decision support; managing the corpus of knowledge, in terms of conflicts, overlaps, and gaps; determining the best ways to deploy various forms of decision support, in terms of their integration with practice and impact on efficiency so that it can be reused in multiple sites, making such knowledge platform-independent. Addressing this last challenge, in particular, is essential to leveraging and making the effort involved in knowledge management economically feasible on a broad scale.

The comprehensive information needs identified by different researchers [11, 13] resume as follows:

- Currently satisfied information needs: information recognized as relevant to a question and already known to the clinician;
- Consciously recognized information needs: information recognized by the clinician as important to know to solve the problem, but which is not known by the clinician; and
- Unrecognized information needs: information that is important for the clinician to know to solve a problem at hand, but is not recognized as being important by the clinician.

Failure to detect a diagnostic problem at all would fall into the latter category. Different clinicians will experience different diagnostic problems within the same patient case, based on each clinician's varying knowledge of patient and unique personal store of general medical knowledge.

One of the difficulty people and machines have relates to tailoring general medical knowledge to specific clinical cases. There might be a wealth of information in a patient's inpatient and outpatient records, and also a large medical literature describing causes of the patient's problems.

The challenge is to quickly and efficiently reconcile one body of information with the other. Clinical diagnostic decision support systems (CDSS) can potentially facilitate that reconciliation. A CDSS can be defined as a computer-based algorithm that assists a clinician wit one or more component steps of the diagnostic process.

These premises form the development framework of MEDIS, a system that aims to incorporate the advantages of the latest technology with the purpose of addressing the challenges and the needs that characterize the clinical environment. The system advances the use of social environments as a mean to leverage knowledge and stimulate sharing, reuse and accessibility for various types of users.

5 Case Study: Clinical Diagnostic Decision Making

The clinical decision stands out as one of the most relevant within the decision-making field, due to its high impact and significant consequences that concern people's life.

A Clinical Diagnostic Decision Support Systems (CDDSS) is designed to impact clinical decision making about individual patients at the specific point in time when these decisions are made [11], [12], [13], [14]. The developers of the CDDSS focused on the prevention of medical errors, the improvement of patient outcomes and of the overall cost of care.

MEDIS is a clinical decision diagnostic support system developed as a pilot project in the attempt to explore the potential of computer assisted decision making in clinical environments based on the advanced technological opportunities.

The system addresses the challenges of providing real-time support and feedback to clinical decision-makers whether they operate in the educational field or in practice-based environments.

The main objectives of MEDIS are:

- To support knowledge acquisition and reuse, and
- To foster optimal problem-solving, decision-making and action in the clinical environment.

Fig. 2. Authentication in the system

MEDIS is a system that can be accessed from desktop and mobile environments to obtain real-time information and knowledge concerning patients, diseases and treatments. It comprises treatment options, customized for each patient based on his medical record.

For example, if a doctor prescribes a treatment that includes incompatibilities with the patient records, the systems automatically signals the problem. This approach is extremely useful as it reduces the number of medical errors and improves the medication.

As the system can be accessed on a limited base within educational institutions, it also sustains the educational process, helping students better their future performance by practicing in a virtual clinical environment.

6 Potential Users of the CDDSS

MEDIS addresses a wide range of users, from medical personnel to patients, teachers and students, from specialized institutions to commercial organizations.

This approach focuses on **e**nlarging the dimension of knowledge collection and reuse, by comprising multiple, heterogeneous sources and by providing suitable knowledge-reuse tools that potential decision-makers can access and assimilate in their daily practice.

To provide a reliable and secure profile, MEDIS provides three different types of access:

- a private section with full access rights: physicians can access only the data of his patients.

- a private section with restricted rights: patients, companies and other institutions can access their own data, while teachers and students can use it for practice-based learning.
  The database 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: provides general information, access to wikis, blogs and medical news, which can be accessed directly through the web application.

7 Main Functionalities of the CDDSS

The decision-support system integrates the following functionalities:

- Patient management that provides the full history of a patient, including treatments, diseases, contraindications, restrictions, recommendations, etc. (Figure 3);

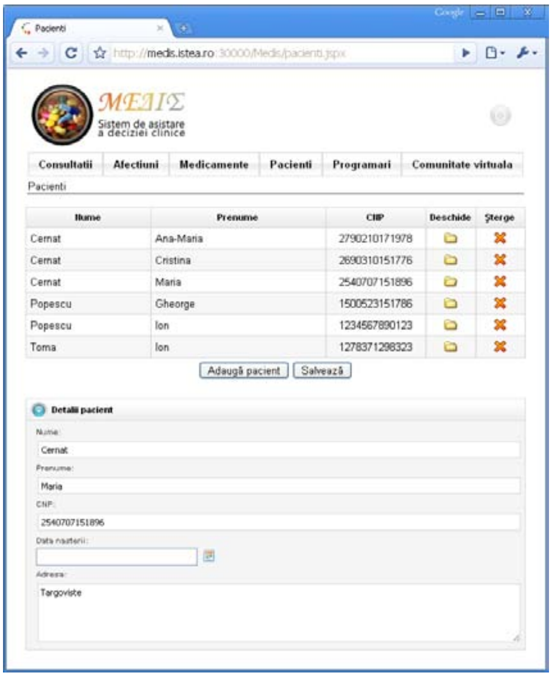

Fig. 3. Patient management

- Diseases management that contains detailed information, recommendations, knowledge and reasoning;
- 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 4);
- Treatment management based on which the system provides automatic alerts to the physician in case of incompatibilities between the prescription, the history of the patient's treatments and the prescribed medication (Figure 5);

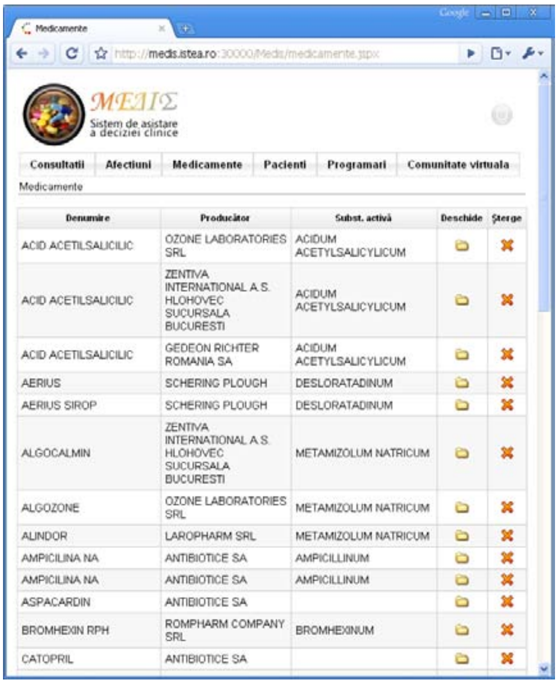

Fig. 4. Medicine management

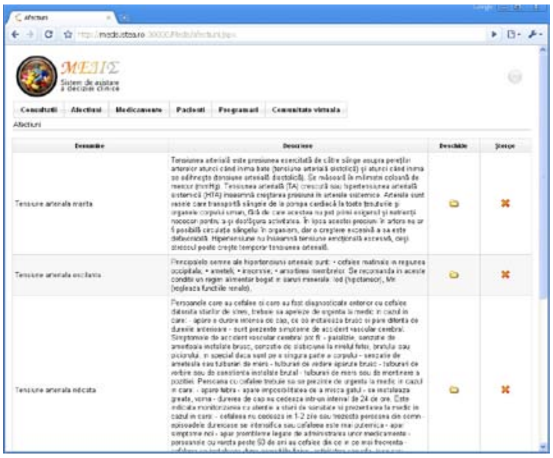

Fig. 5. Treatment management

- Prescription management that synchronize the new prescription with previous consultations the patient had.

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.

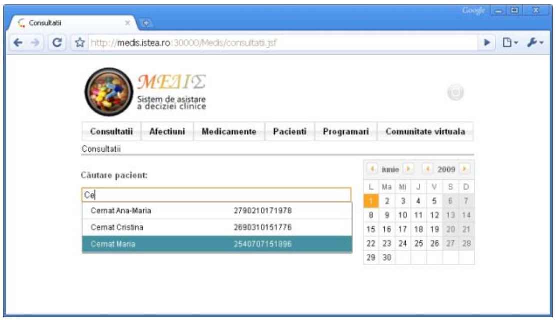

Fig. 6. Search options

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. The search can be simple: by word or phrases; or advanced: by multiple words, using *or* and *no* operators (Figure 6).
MEDIS include comment options that aim to capture timely contextual generated knowledge and facilitate its reuse, by promoting a permanently updated set of knowledge to support clinical decision making. The comments can be private or public.
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.
The advances of information technologies facilitate the development of online collaboration tools. Given the enormous fountain of news bursting from the Internet, the development of MEDIS includes the possibility to comment upon the information or decisions that it comprises. This feature shall be extended to support social technologies that capture the potential of real-time interaction.
MEDIS is available on line at http://medis.istea.ro. It can be integrated in educational environments and used by teachers and students to experience the benefits and the challenges of a CDDSS.
The system can be adapted for implementation in medical institutions, based on the evolution of eHealth parameters at local and national levels that facilitate the collection of data. The performance of CDSSs depends extensively on the quantity and the quality of pre-collected information and knowledge.
Social technologies as decision support tools
The basic functionalities of a traditional CDDSS do not suffice to sustain a better performance. MEDIS has advanced a step forward and has considered the integration of the prosperous social technologies. Forum, wikies and blogs constitute attractive tools for online, synchronous interactivity. At the present, the users can create their own profiles and they can post comments that facilitate guidance within and outside of the system. The user's profile is built to structure links to social tools. This approach eases the burden of knowledge storage within the system, but presents the risks of unavailability of resources out of its control.
MEDIS aims to provide an indexing framework for access to knowledge that resides in online communities. This approach helps users keep focused in their search and reduce the response time within the decision making process.

8 Web-Based Applications

A Web-enables decision support system is a DSS that can be accesses on the World Wide Web via internet. A typical Web-enabled decision support system requires data, a database management system (DBMS), a programming language, and a mechanism for Web-enabling. The DBMS is used to store, manage, and process data, while the programming language is used to build graphical user interfaces, to do complex data processing and presentation, and to incorporate external optimization engines. Several different software packages can be used to build such a DSS. This paper presents the development principles of MEDIS, a web-based knowledge-driven decision support system implemented in clinical settings.
MEDIS was developed using Java. Unlike native applications that access directly the operating system 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 [15], [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 [17], [18].
Most significant development projects involve a relational database. The mainstay of most application is the large-scale storage of information [19], [20]. 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 [21], [22.].
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, the Clinical Diagnostic Decision Support System present in the case study below, have used Hibernate as the database backend because it supports inheritance relationships and various other relationships between classes.

9 Mobile Decision Support

Decisions constitute a permanent challenge, regardless of the environment people operate in or the hierarchical level they activate on. The tools provided through the advances of information technologies address the need to provide timely, qualitatively and cost-efficient information to decision-makers. The emergence of mobile technologies opened new opportunities and helped developers initiate solutions that help decision-makers overcome the barriers of viable accessibility and allow them to perform better when faced with critical events.
The development of mobile application remains a challenge due to the implicit limitations specific to handheld devices in terms of screen size, keyboard dimensions, memory and processing power [23]. The Web sites developed for desktop environments result in a poor or unusable user experience when access in the mobile arena [24].
MEDIS can be accessed on handheld devices, such as PDAs, XDAs, smart phones, and 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 based on the use of advances in mobile technologies.
The developers of MEDIS have taken into account that the delivery of content to mobile devices requires solid customization in the attempt to encourage users to become mobile and to provide an enriched user experience.
Environments such as clinical intervention do not allow decision-makers to wait and perform research, in order to improve the quality of their decisions. Until recent developments, they had to act based on their tacit knowledge. MEDIS advances a test-solution that enables decision actors that activate in ambulatory interventions to have real-time access to patient's electronic health record.
The developers have designed an interface for mobile access that allows decision-makers to instantly learn about their patients' medical background and improve their performance in the decision-making environment. This solution has been adopted because the number of mobile phones has greatly expanded in the last decade and they have been assimilated as a daily facility [25].

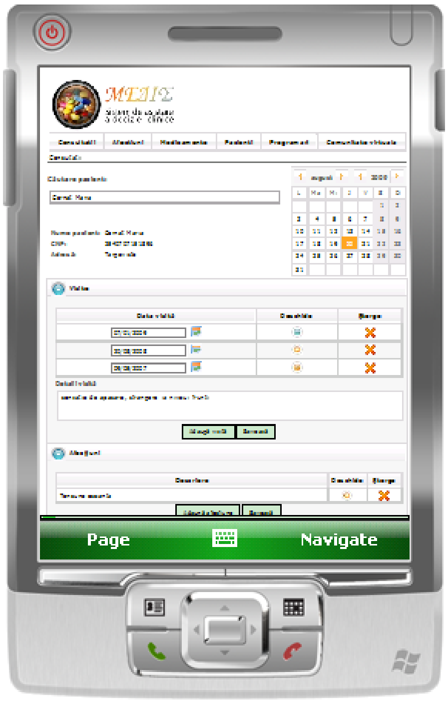

Fig. 7. Mobile interface of CDSS

10 Decision Making and 2D Barcodes

The system provides desktop access to a patient's medical record based on classic user/password authentication. As the mobile arena is restricted by factors that concern limited keyboard dimensions, the developers have implemented a solution based on the use of standard bi-dimensional (2D) barcodes.

Fig. 8. 2D barcodes for quick and secure authentication

The 2D barcode encodes the patient's personal identification information and allows quick and secure 2-factor authentication. First the medical worker's mobile device is configured as a trusted handset and is given a time limited authentication cookie. Usually this cookie will be valid only for the duration of the current shift.
When the system receives a request for information based on the patient's barcode, it first checks to see if a valid cookie is present. Because trusted device have previously been fed with this information, the system can reject all rogue attempts to personal information.
The implementation of this solution is restricted by the adoption of a national standard access card that can sustain the development of low-cost systems for patient identification and provide a wide range of benefits.

11 Agent-Based Technologies

Many methodologies have been proposed to sustain the development and the understanding of DSSs. One of the approaches for developing DSS is agent-based technologies and the authors of this paper have considered sharing and disseminating information pertaining to advancements in theoretical and practical aspects of agent-based DSSs for assisting real-life problems in various domains, as a base for future and value-adding developments in the field of decision-making systems.
In the last years many researches have been focused on DSSs that utilize agent-based technologies for knowledge processing and decision making [7, 26]. The rapid advancement of agent-based technologies has opened up the way for the development of a new and exciting paradigm for the establishing of intelligent software systems operating in dynamic and complex environments. There are a lot of areas in agent-based systems that have attracted attention of researchers. These include formal frameworks for collaboration and cooperation between agents, methodologies for development of multi-agent systems, as well as models and techniques for managing inter-agent relationships (e.g. belief, trust and reputation).
Agent-based technologies have emerged from the field of distributed artificial intelligence. An intelligent agent is an autonomous, problem-solving computational entity capable of operating in dynamic and open environments. Agent properties refer to the fundamental characteristics of agents, which include autonomous decision making and response, with the ability to communicate, negotiate, and cooperate with other agents. Agent-based solutions to a decision-making problem explore agents as autonomous deci-

sion-making units and their interactions to achieve global goals. Some available tools for the development and deployment of agent-based systems include MASDK, JACK, JADE and AgentBuilder [3], [7].
In industrial environments, agent-based solutions are used for real-time manufacturing control problems or complex operation management problems. The application areas suitable for deploying agent-based solutions are real-time control of high-volume, high variety operations; monitoring and control of physically highly distributed systems; production management of frequently disrupted operations; coordination of organizations with conflicting goals; or frequently reconfigured, automated environments.
These perspectives sustain the potential for adopting agent-based solutions for clinical DSSs, in view of the benefits they can provide in terms of feasibility, robustness and flexibility, re-configurability, and re-deployability. At the same time, such endeavors need to consider the barriers of such an implementation that include costs, guarantees for operational performance, and scalability.

12 Conclusions

The world-wide-web contains abundant heterogeneous data sources and decision-makers need to perform under the pressure of this information overload. Information technology has provided new opportunities for the improvement of the decision-making process.
This paper presents the development frameworks of decision support systems and examines a clinical diagnostic decision support system that is currently available for clinicians, for students, and for patients. The paper reveals the potential that such a system has to influence both patient health outcomes and the cost of medical care.
The Clinical Diagnostic Decision Support System that provides real-time access to relevant information and knowledge, and improves the overall performance within the decisional process. MEDIS was developed as a pilot project that applies to different decisional environments and that addresses to a variety of users. The core of its development is based on capture and reuse of knowledge, as a mean to increase efficiency and performance, and to reduce costs. MEDIS incorporates technologies that 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.
The authors have also underlined the emerging technologies that guide the future development of CDDSS and also the challenges that must be overcome if these systems as to realize their full potential. There is still a long way ahead until these systems will be mature enough to be routinely available, not only because there are technical issues that must be addressed, but there are also changes in attitudes that must also occur.
MEDIS is a web-based application that allows users to access the knowledge database anytime, anywhere. The mobile interface provides support for ambulatory decision-making, mitigates more interaction opportunities and expands the usage within the target groups, especially for paramedics that respond to and treat medical emergencies.
The development process has considered the impact and the potential of integrating social technologies within the decision-making environment through tools that facilitate real-time interactions. This feature shall be extended in future versions. The researchers have also considered agent-based technologies as a future development perspective that answers to complex decision-making circumstances.
Overall, MEDIS is defined by unity in diversity, in terms of functionalities, development technologies and users. This integrated approach sustains the quality and the efficiency of decision systems for long term perspectives.

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