Design of a Clinical Decision Support System for Assisting in Empiric Antibiotic Treatments

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Abstract— **The administration of antibiotics is a task that often must be performed in an empiric way due to the pressing urgency of controlling the infection with no possibility of waiting for culture results. Empiric antibiotic treatment is data-intensive, and healthcare professionals must take into account numerous factors (e.g., evidence-based knowledge, economic directives, ecological effects, local conditions and protocols, etc.) before ordering a treatment. Clinical Decision Support Systems (CDSS) have risen with the aim of influencing medical practice and can be an interesting element of knowledge generation in the health information ecosystem. Several examples of CDSS have been developed in the antibiotic prescription field but their lack of flexibility to different settings, and poor adaptability to evolution have been important obstacles for a wider deployment.**

In this work a design of CDSS focused on empiric antibiotic treatment is approached. The design considers the integration of the CDSS in a standard-based healthcare system federation, from which collects real-time data in order to adapt evidence-based guidelines to specific patients, organizational directives and other factors. Semantic technologies have been used as basis of design for enhancing the reuse and flexibility of the system to different scenarios and organizations.

Keywords— **Clinical decision support systems, semantic technologies, antibiotic treatment, data integration.**

I. INTRODUCTION

Clinical Decision Support Systems (CDSS) can be defined as interactive knowledge resources developed to assist in real-time to healthcare professionals, the patients themselves or other concerned in the process of making case-specific decisions related to health [1]. They are aimed to influence medical practice, and some of their potential benefits are cost cutting [2], reduction of medical variability and error [3], and improvement of healthcare quality.

The administration of antibiotics has implications different to any other drug due to several reasons [4][5]. The efficiency of antibiotics (measured in mortality and morbidity index) is far higher than the other kinds of drugs have, and an early treatment with an active antibiotic can reduce the mortality of patients suffering invasive infections [6]. So, detecting patients demanding an early treatment and applying the right one have an obvious clinical impact. The issue is that early antimicrobial treatments have an empiric nature (i.e., in an early stage, the origin of the infection is unknown), and their effectiveness depends mostly on the experience of the health professional and the updated health information about both the patient health and local conditions. In addition, antibiotics are the only substances with ecological effects, i.e., their administration can contribute to the appearance and dissemination of microbial resistances. Thus, strict policies for antibiotic administration must be deployed. Due to such difficulties, the use of antibiotics in health organizations is a hard task with an often inappropriate application [4][5].

There are diverse experiences of CDSS in the specific area of antibiotic use. Some local CDSS have been developed for prescription of a particular drug in specific domains (e.g. ICU [7] or specific infections [8][9]). Some initiatives have obtained positive results but present a lack of flexibility to be exported to other hospitals for being rigidly integrated in the information systems of their hospitals [10]. A relevant example of exportable system is TREAT that uses Bayesian networks to help in diagnosis of determined infections through therapeutic advices [11][12]. In spite of its good results providing evidence-based recommendations, the use of TREAT by healthcare professionals was limited due to it did not include the local habits or conditions that make clinical practice vary from a health organization to another. So, doctors were provided with evidence-based guidelines but not with the rules they were used to, what did reduce the acceptance of the CDSS [10].

Because of the strong variability and continuous evolution of clinical practice, one prerequisite for the broad usage of CDSS and their efficient application to medical settings is the guarantee of a high level of upgradability and maintainability in order to: i) change clinical rules according to their evolution in terms of medical advancements in the treatment of individual diseases; and ii) adapt generic, site-independent clinical rules to the specific patient to be treated [13]. These issues point out two main needs: first, medical knowledge to be embedded in a CDSS should be represented by means of a well-defined and machine-readable language to enable feasible formalization, management and evolution; second, the ubiquitous scenario demands for a technology to share data and structure by granting portability, extensibility and reuse. Finally, CDSS must be able to make useful inferences based on condition-action clinical guidelines and provide some level of

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transparency regarding the mechanisms for reaching such inferences, providing also specific explanations for these medical inferences. Another crucial feature of an efficient CDSS for any health area is the capability of real-time integration of information to provide healthcare professionals with the most suitable, updated and high-quality knowledge for each scenario and patient (and tailored to local health protocols and policies) [10]. A robust and exportable CDSS should take into account a lot of heterogeneous information sources and present mechanisms to coherently integrate and process health data. But often, in non-monolithic environments, there is a wide heterogeneity of information systems (varying among organizations and even within the same organization), and the integration of health information is a current and relevant issue.

In this work a design approach of CDSS focused on empiric antibiotic treatment is showed. The CDSS is not designed in isolation but integrated in a standard-based healthcare system federation. In particular, it is considered a health data transmission based on the ISO 13606 standard and the use of semantic technologies for enhancing the reuse and flexibility of the system to different scenarios and organizations. Other design principles are the adaptability to different scenarios and settings by separating clinical rules from local data, the collection and integration of information in real-time from several sources (electronic health records, local epidemiology information systems, etc.), and the capability of explaining rationale behind a decision, evaluating the results achieved and adapting to improve the rule base.

II. MATERIAL AND METHODS

A. Electronic Health Records (EHR) and the Dual-Model Methodology

EHR are basic building blocks needed for the deployment of efficient CDSS. Several approaches aim to formalize EHR architectures for standardizing health data communication such as EN/ISO 13606 [14] or openEHR [15]. An important contribution of these standards is the two-level modelling approach, that distinguishes a reference model to represent the generic properties of health record information, and archetypes (conforming to an archetype model) which are constraints on the underlying information model used to define patterns for specific characteristics of the clinical data. The principal purpose of archetypes is to provide a powerful and interoperable way of managing description, creation, validation and querying of EHR. The use of archetypes enhances the interoperability of solutions since it provides a uniform access interface to clinical data stored in heterogeneous EHR implementations. In the design approached, an EN/ISO 13606-based health data communication is assumed, and the CDSS queries EHR by means of archetypes.

B. Semantic Technologies

During last decades, semantic technologies have been developed enormously because of the benefits which they provide to distributed systems. One of the most popular semantic tools is the Web Ontology Language (OWL) [16], a knowledge representation language based on description logic and the Resource Description Framework (RDF) representation. OWL allows the specification of domain knowledge by using classes in ontologies. Reasoners or inference engines work over instances of these classes and allow inferring implicit information about the instances according to the domain ontology. Although simple inferences can be realized on OWL, a limitation in the reasoning process exists because OWL does not allow using more complex rules than the inheritance of classes, and a rule language is required. A promising approach is the Semantic Web Rule Language (SWRL) [17], which allows establishing complex relations among properties by extending the OWL expressivity. SWRL supports the construction of "Horn-like" rules expressed over OWL concepts. In our CDSS approach, OWL is used to design and develop an ontology of clinical terms needed to support the CDSS operation. The guidelines of local protocols to be used in execution time are expressed as SWRL rules and processed by an inference engine.

III. RESULTS

A. Design of a CDSS for Assisting Antibiotic Empiric Treatment Tasks

As has been described above, making a decision about the right antibiotic treatment for a patient is an empiric task since healthcare professionals work blindly until they receive the culture results. Meanwhile, the main criterion supporting an antibiotic treatment decision should be the best medical evidence and, if there is no available, expert consensus or recommendations. Due to the complexity of the antibiotic field, medical evidence is a worthy support for healthcare professionals with little knowledge or expertise. But medical evidence is not fully certain. It often provides with a predictive value that must be weighted and grounded on general and local information. Thus, other kinds of information are also needed to make the right decision about a treatment such as symptoms described by the patient, observations and in-situ tests performed by the healthcare professional, historic health data of the patient (previous administrations of antibiotics included), microorganism prevalence and resistance data in the local setting, etiology frequency, and antibiotic administration habits and protocols of the organization.

All that information and knowledge must be properly integrated in execution time with the aim of collecting the most updated information and tailoring protocols and evidence-based guidelines to a specific patient. Our CDSS is designed taken into account the heterogeneity of such information sources. As environment of first approach, a standard-based EHR architecture storing patient data and SQL-based databases for the rest of useful information have been assumed. Other information sources and protocols could be considered but a design based on standards has more possibilities to be interoperable and exportable to different settings. Figure 1 shows the design schema of the CDSS approach for empiric antibiotic treatment although the schema is general enough to accommodate other application domains. The protocols and evidence-based knowledge will be formalized by knowledge experts through the Knowledge Acquisition Interface. A OWL ontology of clinical terms is the support for automatic process, and expert guidelines and recommendations are stored as SWRL rules.

The CDSS is assumed to be available for healthcare professionals in daily practice, being able to use it before ordering an empiric treatment. A doctor introduces the patient identification data and symptoms if it has not been registered before (in that case, all that data would be already stored in the EHR repository and would have to be recovered from there). The inference engine includes such data in the Knowledge Base as individuals of the ontology and performs a first inference step. The possible etiologies (i.e., origins of the infection) for the patient symptoms will be stated. The next step is to collect all the local information to

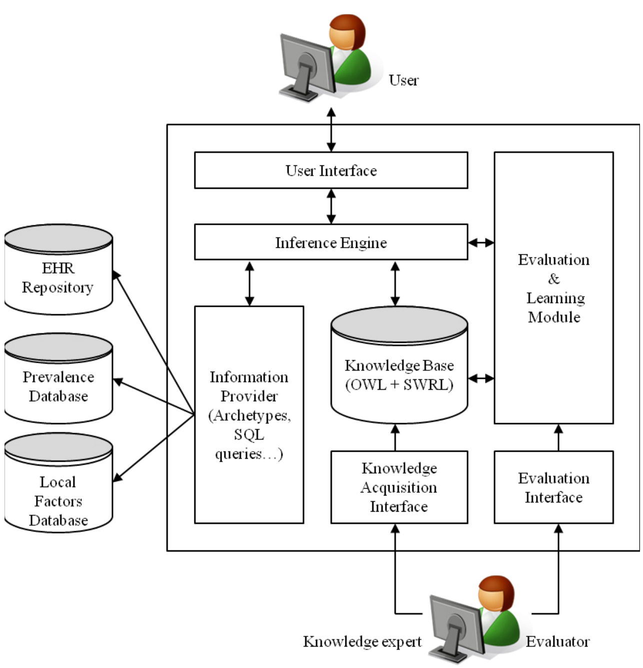

Fig. 1: Design schema of CDSS for empiric antibiotic treatment

weight the different possibilities. The inference engine asks the information provider. This element is the responsible for questioning all the available information sources, integrating the answers and delivering back to the reasoner for a second inference process. Assuming a standard-based EHR repository, EN/ISO 13606 protocol and archetypes will be used to collect patient data. The communication with the rest of dedicated databases will be ad-hoc although a general SQL query/response protocol is assumed. In the Local Factors Database there is data such as the antibiotic use at organizational level (what depends on local professional habits, economic and business decisions, local protocols, etc.); meanwhile the Prevalence Database stores epidemiology data (etiology and microorganism prevalence) at local level.

The collection and integration of all that data within the Knowledge Base are made at execution time, what allows the Knowledge Base to be reused in different organizations, and the CDSS to maintain its flexibility. In addition, other knowledge sources could be queried such as simulation tools running predictive mathematical models or data mining systems.

Finally, the CDSS also includes an improvement component, the Evaluation & Learning Module. Through this component, the CDSS can compare its recommendations with the obtained results (including the subsequent cultures and driven treatment) and re-evaluate the weighting of recommendations, adjusting them if it is necessary. This task can be performed automatically but must be supervised by a knowledge expert. Besides that, the rationale and inference process performed in order to make a recommendation will be registered for evaluation purposes.

B. Preliminary Implementation Results

Although the work presented here is a design approach, a preliminary implementation has been performed. The basic clinical terms for modelling the epidemiology knowledge have been studied, discussed and included in the OWL ontology. Then, the empiric treatment recommendations for several microbiological infections such as pharyngitis and pneumonia have been formalized as SWRL rules. The Protégé-OWL platform [18] has been used to develop the knowledge base (i.e., OWL ontology and SWRL rules). In the current state of implementation, patient data and local factors are introduced manually, and JESS [19] is used as inference engine.

IV. CONCLUSIONS AND FUTURE WORK

In this work a design approach of CDSS focused on empiric antibiotic treatment has been presented. The design considers a CDSS integrated in a standard-based healthcare system federation, from which collects real-time data in order to adapt evidence-based guidelines to specific patients, organizational directives and other factors. The main contributions of this design are the principle of separating clinical rules from local data, and the capability of explaining rationale behind a decision, evaluating the results achieved and adapting to improve the rule base.

Empiric antibiotic treatment is a data-intensive task, and the healthcare professional must take into account numerous factors (e.g., evidence-based knowledge, economic directives, ecological effects, local conditions and protocols, etc.) before ordering a treatment. The approach presented in this work aims to provide a design of CDSS by considering the burden of managing such amount of data by means of, among other elements, semantic technologies. The work presented here is in progress and among the next steps are: assessing the feasibility of the design, studying public archetype repositories, choosing and particularizing those archetypes suitable for the EHR-CDSS communication, implementing health data integration from several sources, and evaluating by knowledge experts. The ultimate objective will be provide the healthcare professional with the most updated and relevant knowledge anywhere and anytime.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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