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Accessing Patient Information for Probabilistic Patient Models Using Existing Standards

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Abstract. Clinical decision support systems (CDSS) are developed to facilitate physicians' decision making, particularly for complex, oncological diseases. Access to relevant patient specific information from electronic health records (EHR) is limited to the structure and transmission formats in the respective hospital information system. We propose a system-architecture for a standardized access to patient specific information for a CDSS for laryngeal cancer. Following the idea of a CDSS using Bayesian Networks, we developed an architecture concept applying clinical standards. We recommend the application of Arden Syntax for the definition and processing of needed medical knowledge and clinical information, as well as the use of HL7 FHIR to identify the relevant data elements in an EHR to increase the interoperability the CDSS.

Keywords. Clinical Decision Support Systems, Standardization, Electronic Health Records, Hospital Information Systems.

1. Introduction

1.1. Decision support for complex diseases

Electronic health records comprise of a lot of heterogeneous patient information. This information is gathered from multiple different sources and exists in different formats. Assessing and comprehending all relevant patient information is a difficult and time-consuming process. It is particularly demanding for complex diseases, especially in oncology. Tumor diseases require interdisciplinary collaboration of clinical experts which makes information gathering even more difficult. In specialized tumor boards, patient cases are discussed by these experts. There are systems being developed to enhance the information access of the physicians, e.g. the clinically integrated Oncoflow system developed by Meier et al. [1].

In the course of personalized medicine specific approaches aim to map patient information to digital patient models [2]. A patient model represents the characteristics and specificities of one patient with a certain disease. In clinical decision support systems (CDSS) digital patient models are used to process and interpret the individual case. The goal is to provide intelligent support for physicians and assistance of cognitive processes in the mind of the user. The support opportunities range from diagnosing a patient to

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suggesting possible therapy options with the aim of finding the most suitable treatment [3].

1.2. Probabilistic patient models

Lemke et al. propose clinical therapy decision support based on Multi Entity Bayesian Networks (MEBN) [*4*]. With a MEBN model specific therapy decisions with all relevant variables can be described. The relations of nodes in a MEBN, representing medical information entities (IEs), are characterized by conditional probability distributions. They represent the magnitude of influence of one IE on another. MEBNs integrate first order logic with Bayesian probability theory. By setting patient specific information (e.g. clinical and pathological examinations), a patient specific Bayesian Network (PSBN) is generated. The PSBN then infers the probability of occurrence for all unobserved variables in the model (e.g. therapy options, complications and quality of life). This approach is implemented with an exemplary model for laryngeal cancer by Cypko et al. [5]. The model consists of over 1000 information entities and more than 1300 dependencies.

1.3. Restricted information access

The information access of CDSSs is restricted by the communication capabilities by the respective hospital information system (HIS). Although communication via HL7 messages is widely implemented by system vendors, methods to apply the information to additional CDSSs are not considered [6]. There are no efficient approaches to utilize patient specific information for probabilistic patient models. Isolated solutions within one hospital, e.g. adapting existing interfaces of a certain HIS to the CDSS, are unrewarding. The same CDSS would not be usable in a different institution.

In July of 2015 the European Commission decided on 27 IHE-Profiles to be referenced in public procurements. This current development has “potential to increase interoperability of eHealth services and applications to the benefit of patients and medical community” [7]. Following the idea of IHE profiles for other clinical use cases, the information access for digital patient models needs to be revised.

2. Methods

HL7 standards provide various methods and tools aiming to interoperability when dealing with patient information. The HL7 messaging standard is internationally accepted for transferring medical and administrative data between application systems. However, the increasing complexity of the standard made it difficult to fully implement [8]. Furthermore, given its main purpose of data exchange, it is not destined for the inclusion of interpretation or conditional evaluation of the information. Other standards of the HL7 international standards organization (e.g. Arden Syntax and FHIR) may suit the purpose of CDSS integration better.

2.1. Arden Syntax

Arden Syntax is a programming language specifically designed to represent and share procedural medical knowledge. In Arden's Medical Logic Modules (MLMs) single medical decisions are implemented to be used in a broader clinical context [9]. MLMs are optimized to be used in decision support systems. With a variety of tools and methods, the clinical information can be processed and enhanced, always considering the specific patient context. This processed information can be used by CDSSs. Arden's principle of fuzziness is a tool for representing medical vagueness [10]. It makes the description of certain medical conditions more accurate.

MLMs can be called by applications but can also place calls and queries back to HIS, e.g. to request data. These calls, however, are not standardized in any way. In so called *curly brace statements* a specific string is transferred to a host system which needs to interpret it correctly. Then, a certain action is triggered, e.g. a data base query. Depending of the implementation, this string may be interpreted differently in a different institution. This circumstance limits the capabilities of exchanging MLMs between different information systems or institutions respectively.

2.2. FHIR

HL7 FHIR (*Fast Healthcare Interoperability Resources*) is a framework currently in development. It aims to combine features from other HL7 specifications, like HL7 versions 2 and 3 and Clinical Document Architecture (CDA). It targets web technologies as a way of transferring information to be applicable in modern application systems, e.g. mobile health applications [11]. FHIR allows the use of RESTful services to communicate and transfer data in the standardized data formats XML and JSON.

The core component of FHIR is called a *resource*. Resources define and identify relevant data elements within an electronic health record (EHR). A resource represents generalized medical concepts, e.g. observation, body site or order entry. Combining different resources allows constituting any clinical use case as needed. Thereby it can solve the issue of ambiguous data element identification in Arden's MLMs.

2.3. System development

Developing CDSSs, we managed to apply Arden Syntax to adapt and process clinical information in our system. MLMs define decision support rules, representing clinical knowledge for an exemplary use case from ENT oncology, the laryngeal cancer model. For example, we implemented MLMs to evaluate the cancer cell infiltration of the larynx using data from different clinical examinations. The information is aggregated and adjusted, so it can be used by our CDSS. MLMs allow quantifying certain information using other data processing methods, e.g. natural language processing, and adding elements of uncertainty as needed. However, when querying the data from the data source (e.g. the database of the patient data management system), our implementation is fixed to the characteristics of this particular system. Exchanging our implementation with another institution would require intense adjustments concerning the data access.

3. Results

As the result of our investigations, FHIR in combination with Arden Syntax is a well-suited technology to integrate CDSSs into existing information system environments. We propose a combination of MLMs and FHIR resources to be able to access information accurately within a CDSS. This approach extends the suggestions of Kimura and Ishihara in [12]. In the following, our system architecture is presented.

We based the CDSS on the laryngeal cancer disease model [5]. Figure 1 illustrates the architecture and communication paths. Our suggested system architecture follows the Medical Information and Model Management System (MIMMS) architecture, proposed by Lemke et al. in [13]. It separates the tools and engines for modeling and model processing from the actual data source and presentation destination. By itself it makes interoperability possible. The probabilistic disease model, based on Bayesian Networks *(a) [see Fig. 1]*, contains all relevant information entities that are needed to evaluate a patient's case and calculate possible therapy options. In MLMs *(d)*, we defined the clinical knowledge that the network considers. For each node we created a MLM that delivers the node specific information. All relevant clinical rules and processing steps are defined. The user selects the patient context *(1)* and respective model *(2)* over a clinical user interface *(g)*. To be able to calculate the PSBN *(f)* the needed patient information is requested via curly brace statements in the appropriate MLM. To enable interoperability and reusability the curly brace statement calls a FHIR resource. Appropriate FHIR templates are stored and filled with references to the desired information when called. References, like patient ID or a SNOMED code for clinical findings, are handed over through the curly brace statements. This allows describing and identifying the needed data elements. These FHIR resources are sent *(4)* to the patient database *(e)* to request the desired information. The corresponding response *(4)* and *(5)* contains the information in the FHIR format, as well. Any information system that integrates HL7s specifications should be able to receive the requests and correctly deliver the information. The information is then assessed by the MLM that requested the data.

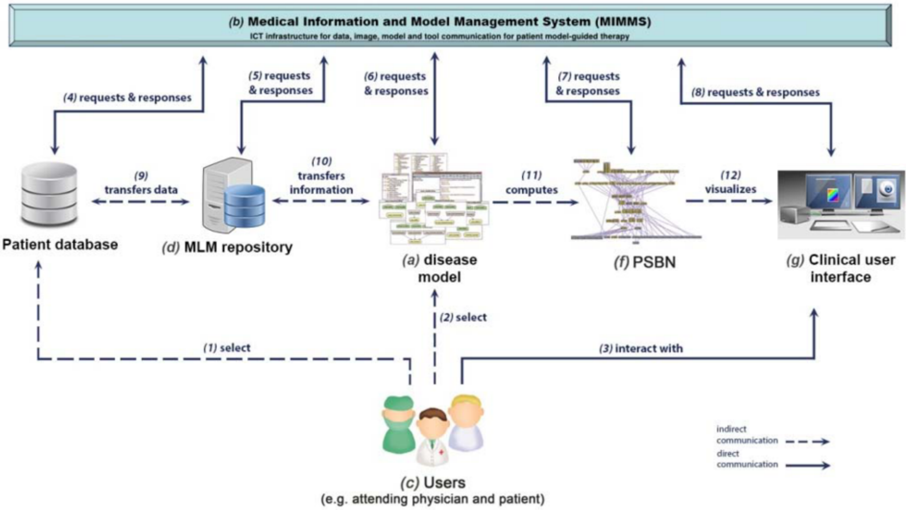

Figure 1. System architecture for CDSS based on Bayesian Networks and access to patient specific data.

Depending on the context that is implemented in the MLM, required calculations are performed on the data, e.g. aggregation of several examinations, quantification of alphanumeric data or fuzzification of uncertainty in findings. This information is handed over to the disease model *(9)*, *(10)* complying with the MIMMS architecture. It is applied to the respective node of the Bayesian Network. Depending on the implementation these nodes expect either numeric values, probability values or even Boolean values, which are provided by the MLMs. The patient specific model is computed *(11)* and the results are transferred to the clinical user interface *(12)* where it is finally presented to the user.

Applying modern communication technologies, e.g. REST, allows our system to be used between different application systems, operating systems and possibly different devices, like mobile tablet computers, as well. Applying standards to the individual elements of the system, like an Arden engine and the way it requests information, increases the interoperability and reusability even more. In addition, separating the definition of clinical knowledge and decision support rules from the data identification and -transfer, facilitates updating and maintaining the CDSS. For example, Medical experts in collaboration with technicians can add new medical knowledge and reasoning while technicians or computer scientists revise the data access.

4. Discussion

Our proposed CDSS combines different standardization frameworks and strategies. With Arden Syntax MLMs we define the medical knowledge and relations to evaluate a patient's case and provide the necessary processing for the calculation of PSBNs. With FHIR resources the needed data elements are defined to precisely identify patient specific information. We aim to enabling the interoperability of clinical data and the reusability of CDSSs in different institutions and hospital information system environments respectively.

MLMs have the advantage that single medical conditions and decisions can be described. Several MLMs, either in a nested architecture or called concurrently, can express very complex relations. The complexity is predetermined by the level of detail in the Bayesian Network. Assessing and processing complex diseases, e.g. laryngeal cancer, implies complex digital models. Our proposed architecture concept combines several technical methodologies. This initially increases the complexity of the disease modeling and system development process. Maintenance efforts increase as well. New medical knowledge, e.g. new diagnostic or therapeutic procedures, requires an adaptation of the fundamental Bayesian Network. For every alteration the corresponding MLMs and FHIR resources also need to be adjusted or new ones need to be added. Yet, to be able to describe a complex disease and assess it in a patient specific context, different elaborate technologies, like Bayesian Networks in combination with Arden Syntax and FHIR, must be applied.

Where Arden Syntax is a well-established standard, used in many decision support systems from different institutions, FHIR is still in development. Its predecessors, e.g. HL7 version 2 and 3, are widely used. FHIR will combine the best features to extend the application possibilities of clinical data communication. On the other hand, relying on standards always depends on software vendors to apply the standards as well. Current developments, like the recognition of IHE profiles on a European level, show that in the future the integration of different information- and decision support systems will be improved.

We will extend our implemented CDSS with effective methods of connecting MLMs with FHIR resources. The goal is to create an added value to routinely recorded patient data by making it available in CDSSs. Thereby we hope to facilitate the physicians' work and increase the patients' safety by finding the best suitable treatments.

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