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Obsah

Electronic Health Record and Telemedicine

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Abstract

According to the objectives of the Ph.D. thesis I have studied the possibilities of electronic health record representation and analyzed the suitability of various data storing techniques. On the basis of the EHR system requirements, e.g. the dynamically modifiable set of collected concepts, I have picked up the threads of my diploma thesis, I have further extended and mathematically formalized them during the work on this Ph.D. thesis and during the research and development in the frame of my employment at the Institute of Computer Science, Academy of Sciences of the Czech Republic, the EuroMISE Centre. I have proposed a completely new *Graph Technology of Medical Knowledge and Healthcare Data Structuralization* that was submitted as an application of invention with a patent request to the Czech Industrial Property Office. I have implemented the stated technology as a data basis of the MUDR electronic health record (EHR) that this paper describes in detail.

Although the MUDR EHR meets practically all the requirements stated for an EHR system, the real practice showed that there are situations when there should be an effortless solution that could be more customized, e.g. for physicians collecting special kind of data for the purpose of a clinical study. As a response to this need I started with research and development of a lighter form of an electronic health record called MUDRLite that provides a functionality to extend the potential and capabilities of the system including advanced user-defined components. The corresponding interface was tested by integrating the *Dental Cross* custom component, whose data model is based on the *Dental-Medicine Data Structuralization Technology Using a Dental Cross* that was also applied for a Czech national patent.

Last but not least, I considered the possibilities of using classical mobile phones as a telemedicine applications' platform. I have analyzed the possibilities of the Micro-Edition of the Java language with the focus on its usage for telemedicine purposes as also described in the paper.

The thesis was submitted with the date of defence set to October 4^{th}, 2005.

1. Introduction

Nowadays, in the medicine area there is still a number of problems and unsolved issues. Many computer scientists keep on trying to find new possibilities of solving various tasks to make the computers serving in the healthcare more effective. The advancement of medical informatics was raised by the ongoing specialization of medical professions and thus the need of sharing information about patients. The development in medicine motivates significantly the usage of information technologies for the purpose of mass data processing in the medical domain. New research topics are emerging, e.g. the optimal representation of a patient record, of medical documentation or of medical knowledge and guidelines.

Medical informatics is understood as a specialization providing complex information services in the public health domain. The importance of this field is increasing constantly as the computer scientists are getting into a new position as a part of a top management of hospitals, pharmacies and health insurance companies. Together with the importance of medical informatics its field of activity grows proportionally. Specific requirements are set on applications in the field of *hospital information systems*, *healthcare registers*, *telemedicine*, etc.

Recently, the *electronic health record* (EHR) has become a crucial part of medical documentation. Its implementation, with a stress on maximally structured information in conjunction with other tools, becomes a basis for *personalized health care* based on *evidence*, *knowledge* and *medical guidelines*. The new possibilities of clinical data sharing have the potential to cut down the number of pointlessly repeated examinations and thus to lower not only the strain on patients but also the expenditures in healthcare. The use of *telemedicine* even enhances those benefits by adding new possibilities of distance care and consultation.

2. The State of the Art

2.1. EHR Standards and Norms

Relevant standards and norms are mainly created by international organizations operating in the health informatics. Any discussion on EHR standards requirements must begin by defining not only the EHR as an entity but also the scope of what constitutes an EHR standard. One viewpoint is that the job of groups developing standards for the EHR is limited to the structure and function of the record and systems processing the record. This is inherent in the structure of many health informatics standards organisations, including *ISO/TC 215*, which typically divide standards working groups into the *EHR*, *messaging*, *terminology and concept representation*, and *security issues*. A broader viewpoint is that EHR standards include standards for all of the EHR building blocks, i.e. the *EHR structure*, *terminology*, *messaging*, *security*, *privacy*, etc.

By far the most important components of healthcare data are clinical data that are directly related to the patient care. Unfortunately, there is currently a massive fragmentation of them. This contributes significantly to the cost of information management, but more importantly, it leads to a lower quality of patient care, ant to more medical errors as well. The focus of EHR standardisation should therefore be to promote a high level of interoperability of clinical information systems within healthcare organisations and between healthcare organisations, initially within individual regions and countries, but global interoperability of EHR systems should be the ultimate aim. Moreover, in order to support future automatic processing and functions like intelligent decision support, the aim must be to build EHR standards, which support not just functional (*syntactic*) interoperability but full knowledge-level (*semantic*) interoperability as well [1].

The major problem is the huge amount of different proprietary or standardized interfaces [2], e.g. *message or interface standards* like HL7, EDIFACT, DICOM, rather *content oriented standards* like LOINC, ICD-10, ICPM or hybrid approaches like CEN 13606, openEHR to name but a few. However, none of the standards is sufficient to cover completely the EHR issues to achieve the high level of EHR interoperability.

2.2. EHR Projects and Best Practices

The research in the field of electronic health record is a matter of great concern to many institutions and working groups. Within the *SynEx* (*Synergy on the Extranet*) project, partners from nine European countries were developing a secure and shareable electronic health record. They used the HTTPS protocol for data exchange purposes and XML for data encoding using the Synapses Object Model, which is similar to the CEN ENV 13606 model. As a semantic for the collectable attributes they used so-called *archetypes* - formal models of clinically relevant EHR elements defining their data structure and terminological basis. The research continued under the patronage of the *openEHR Foundation* and it has defined the so-called *Good Electronic Health Record* (GEHR), which served as an information source for my further work.

Thanks to my employment in the EuroMISE Centre I have learnt the results of the *I4C/TripleC* project where the EuroMISE Centre had cooperated in the past. The I4C/TripleC has developed the *ORCA* (*Open Record for Care*) EHR [3] that also influenced my further work.

2.3. The Main Objectives of the Thesis

According to the assignment the main objectives of this thesis are stated as follows:

- To analyze the suitability of various techniques of electronic health record data representation including multimedia attributes, to evaluate the appropriateness of XML-based trends for communication and other purposes and to consider the possibilities of EHR systems design including the integration of decision support systems in the form of formalized medical guidelines.
- To evaluate the EHR possibilities in the telemedicine area including the possibilities of remote access to EHR systems using mobile devices.

Because of the applied character of this research, pilot implementations of selected software components should become a part of the thesis.

3. Author's Research and Development

3.1. MUDR Electronic Health Record

3.1.1 Architecture of the System: The system is based on a 3-tier architecture with a database layer, an application layer and a user interface layer. The function of the database layer is to store the data and check basic data integrity. The application layer provides a view of the data connected with the corresponding context and without implementation details. The user interface layer represents various client-applications designed mainly for physicians to view and manipulate patients' data. Another type of a client application can be an automated system making statistical processing of the data.

Within the implementation I have split the application layer furthermore. The application layer service communicates directly with the database layer, but it does not communicate directly with user interfaces. There is an XML-based messaging between the user interface layer and the application layer and thus it is advantageous to use the HTTPS protocol to ensure the communication. It would be a pointless effort to develop an own HTTPS server and thus a third-party HTTPS server can be used (e.g. the Apache2 web server).

Optional components of the MUDR EHR system are libraries of formalized *medical guidelines*. These guidelines represent decision support tools integrated to the application layer, however, medical guidelines are updated continuously and thus they should not be integrated to the application layer service tightly. From a special point of view a formalized guideline can be understood as a special type of EHR client application that acquires patient's data. From another point of view it can be understood as a server application that provides a kind of services (its advice) based on the patient's data combined with medical knowledge hardwired in a formalized way. Thus, within the pilot implementation I have designed medical guidelines as dynamic libraries (DLL) that can be linked dynamically to the application layer service. The set of the libraries can be updated continuously without any need of the service recompilation. The same MUDR API is used for the communication between the application layer service and medical guidelines as for the communication with user interfaces. As a pilot test guideline I have formalized and implemented the *1999 WHO/ISH Guidelines for the Management of Hypertension* [4].

3.1.2 Data Representation: The main goal of my work was to suggest common general principles to increase the quality of EHR systems, to simplify data sharing and data migration among various EHR systems and to help to overcome the classical free-text based health record. I did not want to choose a particular database or an operating system and thus I tried to propose an open information storage meta-model with various implementation possibilities as inspirations for EHR software vendors.

Because of the requirement of a dynamically extensible and modifiable set of collected attributes, it is complicated to use a classical relational database structure with columns corresponding to the gathered features as the basis of the information storage. The data representation in the MUDR EHR application uses an entirely new graph technology of which I am the main originator. This *Graph Technology of Medical Knowledge and Healthcare Data Structuralization* was applied as a Czech national patent (application no. PV 2004-1193) in December 2004.

Using this solution the collected attributes and relations among them as well as other medical knowledge are stored in a so-called *knowledge base*. Another graph structure named *data files* is used to store the patient data itself. Both the structures are mathematically precisely described in my Ph.D. thesis or in [5].

3.1.3 User Interfaces: Within my own work I have implemented two thick user interfaces - the applications *EHRClient* and *EHRC*. The EHRClient is a user interface application that enables a simple usage of the MUDR EHR system. The EHRC is a test client application designed mainly for debugging purposes.

In regard to the fact that the development of a comfortable user interface of an electronic health record is a far too complicated issue to be solved by a single man within a reasonable time period [6], there was an extra project assigned at the Department of software engineering of Charles University in Prague, Faculty of Mathematics and Physics that I consulted. The purpose of this project was to develop a user-friendly interface to the MUDR EHR system. The result of this project is an application called *MUDRc* (*MUDR client*) [7] that enables to take advantage of the EHR MUDR system in a flexible and a comfortable way. The MUDRc enables to enter the patients' data by user-defined forms as well as directly into the data files tree. It also includes a simple tool supporting automatic structuralization of data in the form of free-text-based discharge letters (based on regular analysis techniques and results of the diploma thesis of Jiří Semecký [8]). Furthermore, the MUDRc supports the import and export of patient's data, it supports multimedia data types (e.g. images, audio- and video-attributes) and it includes a simple decision support tool. For administration purposes, the MUDRc includes various editors, e.g. the knowledge base editor, the user-rights and policy editor, the forms editor or the output templates editor.

3.1.4 MUDR EHR from the Telemedicine Point of View: A simple solution how to use the MUDR EHR system for telemedicine purposes comes forward. It is based on the implementation of specialized CGI scripts creating various outputs for user interfaces in varied forms. In such a case, the CGI script integrates most of the logic of the client application, which then has just the presentation functionality. In the frame of the thesis I considered the possibilities to implement such CGI scripts for thin clients in the form of web browsers and the Nokia 9110 communicator. In addition, I dealt with the possibilities to implement the MUDR EHR client application running in the T-Mobile MDA device [9]. The research showed that the implementation of a thin client based on CGI scripts generating HTML outputs is realistic. However, the capabilities of such a client are limited. To use such a user interface, it is convenient to fix the knowledge base. It means that we would dispose of a dynamically modifiable and extensible set of collectable features. Actually, it is not really necessary, but in case of a variable knowledge base, we get a disorganized user interface that would be hardly accepted by the physicians' public. Furthermore, we have to face the fact that the web browsers in mobile devices are much more limited than the classical HTML browsers in desktop computers. For example, the HTML browser integrated in the Nokia 9110 communicator supports neither tables nor frames. This fact forces the developer to implement an extra CGI script nearly for each device supported.

As analysing the possibilities of the EHR MUDR user interface running in the T-Mobile MDA device, I have chosen another approach. Using the Windows CE .NET or Windows XP Embedded operating systems we can transfer more of the logic and functionality back to the mobile client device. In this case it is proposed to use the potential of the .NET Compact Framework and implement the communication between the user interface of the MUDR application layer based on .NET Remoting or even more universal version based on web services, which both I have tested with a positive result. The computing power of this modern mobile device brings new capabilities compared to the thin clients based on HTML or the WAP protocol; however, we still have to conform to some limitations compared to a personal computer. The implementation of a complex mobile user interface is quite difficult and time-demanding; a developer has to conform to small displays, limited controlling possibilities, lower operational memory and computing power as well as lower communication speed.

3.2. MUDRLite Electronic Health Record

Currently, most hospitals use an electronic form of health records included in their hospital or clinical information systems. But these systems are often more suitable for the hospital management than for physicians. The health record is not structured as much as necessary, it includes a lot of free-text information and the set of collected attributes is fixed and practically impossible to be extended. Physicians gathering information for the purpose of medical studies have to often use varied proprietary solutions based on MS Access databases or MS Excel Sheets. The usage of the MUDR EHR in such cases is possible, but it may be too complicated and unavailing. Furthermore, the result may not be as user-friendly as a special application dedicated to particular user needs. Those were the main reasons why I started another research and development with the aim to create a light version of an EHR system that would provide just basic functionality and would be extendable according to special needs in a particular environment.

3.2.1 MUDRLite Architecture: The MUDRLite [10] architecture is based on 2 layers. The first one is a relational database and the second layer is a MUDRLite user interface. The database schema corresponds to the particular needs and varies therefore in different environments, in contrast to the fixed database schema in the MUDR database layer. It can be designed using standard data modelling techniques, e.g. the E-R Modelling [11].

All the visual aspects and the behaviour of the MUDRLite user interface are completely described by an XML configuration file, which is loaded by the MUDRLite Interpreter at the beginning. This configuration file specifies directly in its head section the database server that should be used. The MUDRLite Interpreter establishes a connection and asks the user to login. After that the MUDRLite Interpreter creates the user interface consisting of user-defined forms and windows.

The fact that the MUDRLite Interpreter is able to handle varied database schemas often simplifies the way of importing old data stored using different databases or files. Furthermore, this feature enables to tailor the system according to special needs of data collecting in a particular environment or for the purposes of clinical studies.

3.2.2 User Interface and Dynamic Behaviour Specification: All the visual aspects and the behaviour of the MUDRLite User Interface are described completely by an XML configuration file. This file builds the user interface as a set o defined forms with various controls placed on them. Dynamic behaviour and data manipulation are described using the so-called *MUDRLite Language* (*MLL*), those constructs are included in the configuration file as well. The power of the MLL is based mainly on the power of the SQL [12] that the MLL includes. A detailed description of the configuration file and the MLL can be found in my Ph.D. thesis or in [13].

3.2.3 Custom Components and Controls: Additional functionalities can be included by user-defined custom components. It is possible to insert visual as well as non-visual components. Using this feature it is possible to develop graphically advanced components for particular needs in a special environment or computationally advanced components to provide various supplementary potency of the EHR application.

A custom component must fulfil defined requirements to be included into the MUDRLite EHR application. These requirements specify mainly the data exchange rules and policies between a component and the MUDRLite Interpreter. Moreover, a custom component must implement the interface defined and compiled separately in the `MUDRLiteInterfaces.dll` file.

3.2.4 An Example of an Advanced Custom Component: An advanced example of a comprehensive graphical custom component is the so-called *Dental-cross* component that is intended for the application of MUDRLite EHR into the area of dental medicine. This component was ordered to be developed by an external co-operator of the EuroMISE Centre according to a detailed specification, on whose preparation I participated. The data specification of this component determines the data model of the component in the relationship to the MUDRLite Interpreter and the MUDRLite database layer. This model originates from a logical data model that I have designed in close co-operation with other colleagues from the EuroMISE Centre as well as from the Department of Stomatology of Charles University in Prague, 1st Faculty of Medicine and General University Hospital in Prague. In total, it describes 28 independent entities with more than 160 data columns; entirely described in [14] in detail.

Together with these colleagues we have further generalized this model to the so-called *Dental-Medicine Data Structuralization Technology Using a Dental Cross*. This technology was applied for a Czech national patent under the no. PV 2005-229. Furthermore, the Dental-cross component itself demonstrates relatively well the possibilities of data exchange provided by the defined interfaces.

3.2.5 MUDRLite Applicability: The testing of the MUDRLite EHR has demonstrated that this electronic health record is flexible enough and that it allows dynamical changes in the database schema requiring just small changes in the XML configuration file. The two-layer architecture of this EHR separates the user interface from the data storage and in spite of the fact that it is very simple, it is suitable in many standard cases.

The verification and evaluation of the MLL language shows that it is sufficient for many applications, which is mainly because of the power of the integrated SQL. However, some constructs expressed in the MLL language are quite ponderous and thus it is not ruled out that the MLL language will be extended in the future. Possibilities of an extension are for example in the way of including arithmetical expressions or logical conditions right into the MLL.

One of the motivations to develop electronic health record applications is to simplify the sharing and migration of medicine data that is needed among various physicians together participating in the health care of a single patient with the purpose to eliminate pointlessly repeated examinations. A way to contribute to the enhancement of health care quality is to help with overcoming of the classical free-text-based discharge letters. Nowadays, most healthcare providers use a kind of medical documentation in an electronic form of health record. However, the systems used in medical out-patient departments do not often provide sufficient possibilities of data structuralization. The real structured attributes are limited to the first name, surname and birth number of a patient in many out-patient departments of general practitioners (GP). Further structuralization lies in the form of headings of different parts of a discharge letter and the GPs are lucky to have the name and birth number automatically assigned to various documents, e.g. to an order form accompanying the patient to a specialist [15]. But from the computer scientist point of view this is not sufficient. Many physicians do not realize that they could expect more but this relates to the fact that no one has offered them anything more. We can not be surprised that physicians, who need to collect specific data (e.g. for the purpose of a clinical study), use various proprietary data storing methods that are often based on ”office-software” tools, e.g. the MS Word, MS Excel or MS Access tool. During my studies I have seen a few of technically advanced physicians who have designed and created a MS Access database themselves. However, such a database was often in the form of a single disorganized table containing many various columns breaking ”all the database normal forms”. But the fault lies not on the physicians; it lies on the computer scientists who do not support the physicians enough.

The MUDRLite EHR system, which I present as a partial result of my Ph.D. thesis, represents a relatively simple solution of creating an electronic health record tailored to special needs in a particular situation. First of all, it can be used as an advanced tool for collecting of medical data, but it does not have to be limited for this purpose. Mainly thanks to the defined interface that enables the integration of custom components, it is possible to start with a simple tool used to collect medical data and extend it step by step to an advanced EHR system according to special needs.

3.3. Telemedicine Applications on Mobile Phones

Lately, we have been undergoing a significant progress in the field of mobile telecommunication. Rarely do we meet a person who does not possess a mobile phone. The progress in the telecommunication area goes together with the progress in the field of information technologies. The computing power of microprocessors commonly used in mobile phones overtakes multiply the powers of computers controlling first flights to the

Universe. A mobile phone is not just a phone anymore; it becomes an indispensable tool providing the range of services and tools, e.g. a diary, a notebook, a calculator, an alarm clock, a dictaphone, a camera, and much more. It often enables the Internet access using a WAP or an HTML browser and an email client application, it supports data connection using GPRS or HSCSD and it enables an interconnection to a computer using a cable as well as wireless using of IrDA or Bluetooth technologies. The continuously extending potential of mobile phones was the main motivation why I have analyzed the possibilities of the usage of a mobile phone as a platform for telemedicine applications. Since the mobile phones vendors frequently implement Java support into their mobile phones, it was of concern to my Ph.D. thesis and it is detailed described in it.

3.3.1 Java in Mobile Phones: Lately, the word Java is inflected in all grammatical cases in the connection with mobile phones. The Java term often identifies an object-oriented programming language with libraries of standard classes and sets of application interfaces. This set of libraries and interfaces exists in three different editions, *Java2 Enterprise Edition* (*J2EE*), *Java2 Standard Edition* (*J2SE*), and *Java2 Micro Edition* (*J2ME*). As one would guess, J2ME is the relevant edition from the mobile phone point of view. J2ME was created with the purpose of harmonizing the Java support in small devices including not only mobile phones but also other electronic devices. Therefore, J2ME is not a complex uniform specification, yet it is divided into various configurations. A configuration specifies a basic set of libraries and device features and it is further refined by so-called profiles. Each specification [16] determines the minimal hardware configuration of a device supporting it. For the purpose of telemedicine applications on mobile phones the *Connected Limited Device Configuration* (*CLDC configuration*) is relevant. It specifies the minimum of 128 kB of a permanent memory, which content must be preserved while switched on as well as switched off (but from the custom application point of view it does not have to be writeable), and the minimum of 32 kB of the memory that must be at virtual machine disposal. The device must dispose of at least a 16 bit processor (RISC/CISC) running at least on the 16 MHz frequency.

3.3.2 Mobile Java Applicability: Although the mobile Java is used mainly as a platform for various games nowadays, the analysis shows that this smallest Java edition will find its use in the telemedicine field in the future. However, it must be admitted that a small display and just a few of input keys limiting the controlling possibilities will probably be always limiting factors for comfortable and user-friendly applications. The mobile phone manufactures are not in an easy position, the users want to get a larger and more colourful display and the keys should not be too small, but the phone itself should become smaller, lighter and more powerful. For a telemedicine J2ME application the limiting factors lie in the mobile phones' hardware as well as in the software. The size of the application is strictly limited. The possibilities regarding the CLDC 1.0 and MIDP 1.0 specifications are limited as well. In developing MIDP 1.0, the specification authors were very conservative in the functionality they chose for the base profile. The absence of any type of standard security functions, in particular, proved to be very limiting. Nevertheless, the first mobile phones supporting the MIDP 2.0 profile emerged on the Czech market. This specification enables some low-level facilities, e.g. the TCP/IP sockets or even the UDP datagrams and it enables the secure HTTPS connection as well. In addition to that, the MIDP 2.0 profile rectifies the security issue through the introduction of WAP Certificate Profile (WAPCERT) support, based on the Internet X.509 Public Key Infrastructure (PKI) Certificate and the Certificate Revocation List (CRL) Profile. The introduction of PKI functionality is utilized by MIDP 2.0 to provide secure connections and digital signatures for trusted MIDlets. Trusted applications are permitted to use APIs that would otherwise be restricted by MIDP 2.0's enhanced security model. This convinces me that using the MIDP 2.0 telemedicine applications in mobile phones become a common reality in the future.

3.3.3 A Pilot Mobile Application: While analysing the possibilities of J2ME applications, I asked myself whether it would be possible and realistic to develop a full EHR client application, e.g. a kind of MUDR user interface. Unfortunately, nowadays I have found out that this is unrealistic mainly because of mentioned limitations. However, the J2ME may be sufficient to develop some simpler telemedicine applications. Thus, as a demonstration I have formalized the – already mentioned – *1999 WHO/ISH Guidelines for the Management of Hypertension* [4] into a form of pilot J2ME application, which can be launched in most mobile phones supporting Java. A more detailed description including a simple manual how to download, install, and try in one's own mobile phone can be found in the article [17].

4. Conclusion and Summary

According to the objectives of the Ph.D. thesis I have studied the possibilities of electronic health record representation and analyzed the suitability of various data storing techniques. On the basis of the EHR system requirements, e.g. the dynamically modifiable set of collected concepts, I have picked up the threads of my diploma thesis [18], I have further extended and mathematically formalized them during the work on this Ph.D. thesis and during the research and development in the frame of my employment in the Institute of Computer Science, Academy of Sciences of the Czech Republic, the EuroMISE Centre. I have proposed a completely new Graph Technology of Medical Knowledge and Healthcare Data Structuralization. Within this research my colleagues Ing. Petr Hanzlíček, Ph.D. and Prof. RNDr. Jana Zvárová, DrSc. have supported me with valuable pieces of advice and together we submitted this technology as an application of invention with a patent request to the Czech Industrial Property Office in December 2004 (application no. PV 2004-1193). I have implemented the stated technology as a data basis of the MUDR electronic health record where I have also verified the applicability of contemporary XML-based communication trends and used XML as the basis of the MUDR API interface.

It is a difficult task to harmonize all the requirements stated for en ideal electronic health record application. Thanks to the graph data storage technology the MUDR EHR meets the requirement of a structured way of data storage combined with free text information storage possibilities, the requirement of the dynamicity of the system, mainly in the way of modifiability of the set of collectable data and the requirement on the integration of pedigree information for the purpose of a patient's family history. This technology is multilingual and it enables to associate patient's data according to the events in patients treatment or life. It includes an administrative record about all changes concerning patients' data and a record about the origin of any piece of information. It integrates multimedia data, e.g. audio and video records, images, and other unspecified binary types. Furthermore, the technology enables defining of access control policies encoded in the knowledge base, which even increases the security provided by the database systems themselves.

I participated in the leadership and consulting of a software project in the Department of Software Engineering, Faculty of Mathematics and Physics, Charles University in Prague, that resulted in an advanced user interface of the MUDR EHR. This user interface called the MUDR client (MUDRc) [7] represents a thick client application supporting data structuralization by user-defined forms and by a specialized tool enabling to use a set of user-defined regular analysis rules to structuralize data from free-text-based discharge letters. The MUDRc integrates the support of data visualization and evaluation, it enables to define various types of templates for various types of data reports, prescriptions, and other documents and additionally it includes a special statistical module retrieving descriptive statistics about the population stored in the EHR system. The interface including such a module is open and thus it is possible to add more modules in the future and extend the functionalities hereby. Furthermore, the MUDRc enables an easy way of data verification according to a user-defined set of integrity rules and it mediates consulting the health record of a particular patient with formalized medical guidelines running as decision support tools at the MUDR application layer. For the MUDR EHR I have proposed the methodology and interfaces to formalize medical guidelines, which enable to integrate them as a part of the MUDR application logic. As a pilot test I have formalized and integrated the WHO/ISH Guidelines for the Management of Hypertension [4]. The other possibilities to integrate medical guidelines formalized by the GLIF model were onward considered within the diploma thesis [19].

To extend the applicability of the MUDR EHR with the stress on support in the telemedicine area, I have further analyzed the possibilities how to implement both the thin MUDR mobile clients (HTML / WAP) and the thick MUDR mobile clients (PDA and similar devices). For the purpose of this analysis I have implemented several software components, which showed the barriers. The implementation of a complex mobile user interface is quite difficult and time-demanding; the limitations of small displays, controlling possibilities, operational memory, and computing power imply that it might be necessary to maintain a good arrangement of the user interface to fix the set of collectable features or the whole knowledge base.

Although the MUDR EHR meets practically all the requirements stated for an EHR system, the real practice showed that there are situations when there should be an effortless solution that could be tailored to special needs of the particular environment, e.g. for physicians collecting special kind of data for the purpose of a clinical study. As a response to this need I started with research and development of a lighter form of an electronic health record called MUDRLite [10], [13] that abandons the challenge to meet all requirements coming with a completely different approach. The MUDRLite EHR system is designed with the goal to provide simply the services that are needed in a small special environment and no others. The research resulted in another pilot application that simplifies the system architecture as well as the data storing principles. Furthermore, thanks to the easier conception, which enables the database schema to be user-defined, the data import possibilities are easier. However, it provides a functionality to extend the potential and capabilities of the system including advanced user-defined components that could for example enhance the security or ensure the interoperability with various other systems.

The interface was tested by integrating the Dental Cross custom component to the MUDRLite EHR system in the domain of stomatology. This component was developed by an external contractor of the EuroMISE Centre, however its data model origins in the Dental-Medicine Data Structuralization Technology Using a Dental Cross. Together with other colleagues from the EuroMISE Centre as well as from the Department of Stomatology of Charles University in Prague, 1st Faculty of Medicine and General University Hospital in Prague we have applied it for a Czech national patent under the application no. PV 2005-229.

Last but not least, I considered the possibilities of using classical mobile phones as a telemedicine applications' platform. Lately, we have been undergoing a significant progress in the field of telecommunication. A mobile phone becomes an indispensable tool providing range of services and frequently implementing support for applications in Java. Therefore, within my Ph.D. studies I have analyzed the possibilities of the Micro-Edition of the Java language with the focus on its usage for telemedicine purposes [17]. The limitations that I have described in this thesis make it impossible to develop a complex user interface of an EHR system. However, it does not mean that there is no J2ME applicability in telemedicine. As an example how to implement a telemedicine application for a mobile phone using the Java2 Micro Edition I show formalizing of the mentioned hypertension guidelines [4] as a J2ME application that everyone can test for themselves [17].

In general, I considered many electronic health record issues as well as telemedicine application issues. Some new technologies and pilot software applications were created and can be used as a motivation while developing commercial products.

The thesis was submitted with the date of defence set to October 4^{th}, 2005.

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