Grid-supported Medical Digital Library

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Abstract. Secure, flexible and efficient storing and accessing digital medical data is one of the key elements for delivering successful telemedical systems. To this end grid technologies designed and developed over the recent years and grid infrastructures deployed with their use seem to provide an excellent opportunity for the creation of a powerful environment capable of delivering tools and services for medical data storage, access and processing. In this paper we present the early results of our work towards establishing a Medical Digital Library supported by grid technologies and discuss future directions of its development. These works are part of the "Telemedycyna Wielkopolska" project aiming to develop a telemedical system for the support of the regional healthcare.

Keywords. Telemedicine, e-health, medical digital library

Introduction

"Telemedycyna Wielkopolska" is a project run in an interdisciplinary collaboration between Poznan Supercomputing and Networking Center, the Institute of Computing Science of Poznan University of Technology, and the Division of Trauma, Burns and Plastic Surgery of Poznan University of Medical Sciences, which aims to design and develop a system for provisioning telemedical services in the Wielkopolska province [1]. The objective of the project is to propose a set of remote services that will support the regional health care. Although the system and the tools are designed to be used by various medical domains, the pilot use case scenario is based around services for the support of trauma treatment. To this end a system of medical teleconsultations in the area of trauma has been designed and deployed as a pilot for use within several hospitals in Wielkopolska. Further works of the project focus on developing a multimedia Medical Digital Library that will store and enable information and knowledge in the area of trauma.

This digital library makes use of the infrastructure developed in the recent years by the academic community in Wielkopolska and allows to deliver a huge amount of useful information to the regional medical community to support them in their everyday work and to widen their knowledge and thus improve the quality of patient treatment. It also allows to construct value-added services that can support such different activities as medical research or health care system management. In this paper we present the concept and the first results of the development of the Medical Digital Library which was based on the grid infrastructure enabled through the research and deployment performed in the recent years. The grid infrastructure utilized for the needs of the Medical Digital Library is discussed in section 1. Section 2 presents the first

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service of the Medical Digital Library that has been deployed for use by the medical community: the Registry of Reference Medical Cases. Other services developed currently and planned for the future are discussed in section 3. We end with conclusions in section 4 where we also draw on some work related to our research.

1. Grid Infrastructure for the Support of the Medical Digital Library

As it was mentioned in the Introduction, the Medical Digital Library is supposed to store and give access to a huge amount of healthcare-related data. This imposes a requirement for delivering an infrastructure capable of efficient storing of this data to the hospitals in the Wielkopolska province. This infrastructure must enable secure sharing of information between the system participants. One should also consider limited investment funds that are available to the healthcare system in Poland. It is the academic community which obviously plays a significant role in supporting the public services.

The Wielkopolska academic community has a long list of success stories connected with the cooperation with public organizations responsible for various areas of public activities such as e-administration [2], hospital informatization [3] or e-safety [4]. The academic community is the owner and operator of powerful infrastructure that can be put to use for the support of the public services such as, for example, health care. This infrastructure includes the broadband optical network named PIONIER [5], and a significant amount of computing and storage resources that were enabled on the grid as a result of several national and international grid research projects conducted in the recent years.

The remote resources enabled on the PIONIER network through advanced grid technologies [6] provide a great opportunity to deliver an infrastructure for the support of the regional Medical Digital Library. More importantly, this infrastructure based on the grid fulfills both the technological and the budget requirements connected with the organization of such a library in Wielkopolska. In this section we discuss several key elements of the grid-based infrastructure that is utilized for the support of a developed distributed digital library.

1.1. Data Storage

One of the most important requirements for the infrastructure supporting the developed Medical Digital Library is the capability of secure and efficient storage of huge amounts of various types of data. This data includes simple textual information, various types of medical images and video files. Moreover, the sources of this data are diverse and range from text and image information entered via a web portal, through DICOM medical images and sequences saved at the point of patient examination, to digital recordings of events such as medical operations. These sources are distributed across individual hospitals and across the region, and often produce sensitive personal data.

The data storage resources owned by the Wielkopolska academic community have been enabled on the grid through the Gridge Data Management System [7]. The system has been designed within the PROGRESS project [8] and further developed within such projects as SGIgrid [9] or ACGT [10]. It will also be used for the construction of the National Data Storage infrastructure [4]. Thanks to the unified access to data storage resources, which is based on the grid standards, it has been possible to enable a

huge virtual storage resource incorporating not only the resources locally available in the Wielkopolska province, but also other resources resulting from the deployment of grid infrastructures within the above-mentioned projects.

The Gridge Data Management System provides mechanisms for file virtualization on the grid. It offers its functionality via GSI-based Web Services that allow to manage the stored files, metadata and file access rights. The physical data is stored within the so called Data Container modules which are also GSI Web Services and enable storage of data on various types of media: generic file systems, tape archivers or relational databases. The transmission of data to and from the system takes place with the use of various data transfer protocols such as, for example, Grid FTP or GASS. Integration of new types of Data Containers and new data transfer protocols is relatively easy thanks to the flexible API system. The Gridge Data Management System is used to enable the above-mentioned distributed data storage resources to be used within the constructed Medical Digital Library. This grid data infrastructure is used to store and share such data as medical images and image sequences, and recordings of various events.

1.2. Data Processing

Putting the data stored within the Medical Digital Library on the grid is also dictated by the need to process the collected data by various applications. These applications will search for knowledge links between individual sets of data and will be used for such scenarios as clinical decision support or medical research. It is envisaged that the developed Medical Digital Library will eventually grow to hold a huge number of data records, thus imposing a significant computing power requirement. Such computing power, just like in the case of data storage resources, is available within the grid infrastructure managed by the academic community that resulted from the national and international grid projects. In addition to the resources resulting from the execution of the already mentioned projects, this infrastructure also includes the GridLab [11] and Crossgrid [12] grid infrastructures.

Apart from delivering a utilizable grid infrastructure, the GridLab project resulted in developing a range of valuable grid technology. This includes the Gridge Resource Management System (GRMS) [13] which allows to manage and access computing resources such as hosts and applications. It offers a GSI Web Services API to submit grid jobs, and hides the complexity of the underlying low-level grid management software. GRMS cooperates with such grid management systems as Globus Toolkit [14], Sun Grid Engine [15] and Unicore [16].

1.3. Security

An important issue of the Medical Digital Library is data security. This includes secure access to the data with the support of a flexible rights management mechanism, secure transmission of data and data integrity. The data and computing grid infrastructure described in the previous two subsections is managed by and accessed via Web Services based tools that expose their functionality in compatibility with the Grid Security Infrastructure [17]. This allows secure communication between the services involved in the realization of a transaction requested by the user and allows single sign-on on distributed resources. Each of the Medical Digital Library users has his/her personal certificate issued by the Polish Grid CA which he/she uses to authenticate into the library.

Further on, the authorization of user operations on resources is maintained by the Gridge Authorization Service (GAS) [18]. GAS is a flexible service that allows to apply different types of authorization policies for different services based on resource centric or role centric models. It can authorize actions for multiple services concurrently. In the Medical Digital Library GAS is used to authorize access to computing grid resources and to library services such as, for example, the Registry of Reference Medical Cases which is described in detail in the next section.

1.4. Data and Service Access

Data and services of the Medical Digital Library are accessed from within various types of user applications. The major user access point is a web portal, but some scenarios involve usage of mobile user interfaces or standalone applications. To enable services such as the already mentioned Registry of Reference Medical Cases or the Medical Teleconsultations Service within various types of user access applications, these services have been realized in line with the Grid Service Provider concept [19, 20]. The Grid Service Provider introduced a flexible architecture of accessing grid services at high-level of granularity to facilitate construction of grid user interfaces. This allows to build user access points on various types of terminals including web browsers, desktop computers and mobile terminals relatively easily.

The "Telemedycyna Wielkopolska" portal, the main user access point, has been deployed within the GridSphere Portal Framework [21] and utilizes its capabilities for building standards-based portals. The telemedical services enabled within this portal also take use of the functionality of Grid Portlets [22], especially in the area of GSI communication with remote services. The mobile terminal is used for the Teleconsultations Service and is planned for delivering clinical decision support at the point of care. The standalone user interface is connected with archiving medical images such as DICOM images and operation recordings.

2. Multimedia Registry of Reference Medical Cases

The Registry of Reference Medical Cases is the first service of the developed Medical Digital Library that has been delivered within the "Telemedycyna Wielkopolska" portal. This aim of this service is to provide functionality for collecting and classifying medical cases in the following two usage scenarios:

- collecting reference medical cases, i.e. such cases that are examples of ideal treatment applied to cure specific injury suffered by a patient;
- collecting all medical cases in the Wielkopolska province that were subject to treatment in the surgery divisions of Wielkopolska hospitals.

Currently the first of these two scenarios has been enabled within the portal. The pilot registry has been deployed to form a library of reference medical cases in the area of trauma.

2.1. The Registry Structure

The Registry of Reference Medical Cases is composed of the following four core elements:

- the medical domain database which holds descriptions of medical domains supported by the particular instance of the registry;
- the UI database which keeps information on UI feel and look for a particular type of end-user terminal in correspondence with the structure of a case belonging to a related medical domain;
- the case database where the actual descriptions of medical cases are stored;
- the data grid resources enabled via the Gridge Data Management System services which store multimedia illustration of the collected cases, such as medical images or video documentation.

The purpose of the medical domain database is to allow easy instantiation of a new registry for the support of a medical domain previously not supported by the Medical Digital Library; the information required to describe a medical case highly depends on the medical case to which it belongs. The domain database allows to use metadata to describe the structure of a medical case connected with a particular domain. The UI database allows to enter information corresponding to the structure of a medical case connected with a particular domain and is later used within the end-user application to construct a user interface. It is very useful to automatically generate the user interface within the portal or a standalone application while enabling on-the-fly modifications to the functionality of the interface when the structure of the medical case changes. Both these databases are stored in a relational database system.

The case database is a place where the descriptions of the actual medical cases are stored. Each medical case description contains basic information on the patient, the results of patient examination, classification of the case according to the standards agreed within the community and the information on the applied treatment. These descriptions are stored in a relational database system. The medical case description is accompanied by the multimedia illustration of the case, for example by medical images or video documentation. These data files are stored on the data grid.

2.2. The Portal Interface

The Registry of Reference Medical Cases is designed in accordance with the Grid Service Provider pattern. It is a Web Service supporting the Grid Security Infrastructure. Its primary access interface is the “Telemedycyna Wielkopolska” portal, but it is also planned to enable some of the functionality on mobile terminals. It will also be possible, in case such a requirement turns up, to enable this service within standalone end-user applications.

The web portal interface of the Registry has been developed as two JSR-168 portlets: one for adding and modifying entries in the Registry and the other for browsing and searching through the Registry. The portlets are compliant with the standards and as such they can be potentially deployed in any JSR-168 compliant portal framework. As it was already mentioned above, we selected GridSphere as the portal engine in which the “Telemedycyna Wielkopolska” portal runs. Selecting GridSphere for the portal framework is connected with both its functionality that fulfills all the requirements for the portal and its full compatibility with the Gridge Toolkit which was used to build the grid infrastructure utilized by the constructed Medical Digital Library.

The Registry is currently used as an education resource for medical doctors, especially surgeons in the Wielkopolska hospitals. The reference cases are provided by the experts in the area of trauma. It is planned to integrate this service within the

Medical Teleconsultations scenario to allow the users to access a simple ‘show me similar cases’ decision support mechanism and to allow the consultants to point to the Registry entries as a reference within their consultation answers.

2.3. Value-added Services

Introduction of the Registry of the Reference Medical Cases allows us to start the development of some value-added services on top of this core service of the Medical Digital Library. As it was already mentioned, the service can be used not only for collecting the reference medical cases, but it can also be used to collect all the medical cases encountered in the region in the area of the medical domain in question. It is important to note, though, that the organization of this scenario requires a discussion within the medical community so that the collection of data can be possible.

The two scenarios we envisage as those that can be supported by accommodating the developed Registry to collect all medical cases are as follows:

- medical research in which scenario the collected data may be subject to medical research conducted by the researches at the Poznan University of Medical Sciences;
- healthcare system management support in which scenario the collected data may be analyzed to report the current trends in the medical domain in question, thus helping to better estimate needs of the regional health care.

We envisage to employ the computing grid resources to support users working within the above-listed scenarios.

While the deployment of the scenarios in question is relatively easy from the technical point of view assuming the data is already stored in the Registry, one should remember that it also requires developing and implementing protocols for the exchange of information between the hospital information system software used in Wielkopolska and the Registry to facilitate data collection .

3. Other services

The Registry of Reference Medical Cases discussed in the previous section is the first service of the Medical Digital Library that was successfully delivered to the end-users. We are currently working on adding new services to the library. The services that we plan for addition to the Library include the medical data archiving on the data grid and knowledge discovery for clinical decision support. We discuss these two services in this section.

3.1. Medical Data Archiving on the Grid

The archiving of medical data is connected with the requirement received from the medical community to support the hospitals with a cost-effective solution for a PACS system [23, 24]. A natural solution for this type of a system in the “Telemedycyna Wielkopolska” environment is to organize the PACS system on the base of the data grid infrastructure; a similar solution has been proposed by B. J. Liu, M. Z. Zhou, and J. Documet in [25]. To this end we began investigation towards establishing an easy-to-use solution that would seamlessly integrate with the Gridge Data Management

System on the one hand, and with the telemedical services provided within the "Telemedycyna Wielkopolska" portal on the other hand.

The medical data that is subject to storing in the data grid includes the following:

- the image documentation of patient examinations conducted with the use of various types of medical modalities such as, for example, computed tomography, radiography, magnetic resonance imaging and others;
- the digital recordings of events taking place at the hospitals such as, for example, operations performed in the operation rooms.

The long-term purpose of storing these types of data is as follows:

- storage of the DICOM documentation scenario will allow to organize a region-wide archive of radiology documentation which will be accessible to all medical doctors in the province, with a special focus given to the general practitioners;
- the archiving of the course of events during operations will have two applications: the first application is to use the selected recordings as education materials, the second one is to support solving disputes over medical errors.

Both these scenarios will improve safety of the patients and the overall quality of healthcare in the region.

To enable storage and access to the above-listed data types on the data grid we are planning to integrate a DICOM image and a video streaming servers with the Gridge Data Management System as two new protocols for data file transfer. This will allow to easily and immediately serve the data in question embedded within web pages once they are accessed.

The medical data archiving on the grid scenario is currently under design. We expect the first results at the end of February when pilot deployments of the scenario take place.

3.2. Knowledge Driven Decision Support

The data collected with the Medical Digital Library may be a subject of deep analysis aiming at discovering knowledge. A simple example of data analysis is search for medical cases similar to the one currently viewed or processed by a user. In this scenario knowledge discovery is relatively easy to design and implement. However, searching for similar information will go well beyond simple matching pieces of information with well-defined structure such as, for example, results of examinations or classification of a medical case found in the Registry of Reference Medical Cases. It will also apply domain knowledge to evaluate similarity between cases and to search for similarity within the multimedia medical documentation, with a special focus given to image analysis .

Building the domain knowledge will require constant processing of new data to update the knowledge base. This processing of data is envisaged to take place on the grid, which can especially help with the analysis of images as experience of other projects such as, for example, Mammogrid shows [26]. The knowledge collected and constantly updated during the data processing will help to create another service of the Medical Digital Library. This service will be responsible for supporting clinical decision making, including suggesting clinical decisions at the point of care in the 'anytime, anywhere' scheme with the use of mobile terminals. The applications in the area of the clinical decision support are a subject of research by our colleagues from the

Institute of Computing Science of Poznan University of Technology, who have previous experience with constructing such services [27].

4. Conclusions and Related Work

The Medical Digital Library that we discussed in this paper is at early stage of construction. It is envisaged to support the health care in the Wielkopolska province thus improving the quality of treatment received by the patients in the region. The Library is a part of the "Telemedycyna Wielkopolska" system which aims to provide a set of remote services built on top of the optical network and grid infrastructures. The early results of the project show that utilization of the grid infrastructure and grid technology has a big potential providing opportunities to deliver huge data and computing resources that can be cost-effectively used by the healthcare organizations such as hospitals.

Summing up the discussion it is important to draw on other medical digital libraries found in the world. Some examples include the "TeleMedical.com" digital medical library [28] where one can find all sorts of digital medical information ranging from publications in the area of medicine to symptoms, diseases and medications databases. Interesting work has been conducted by Papadakis et al. [29] who designed an architecture for a secure web-based digital library. A medical digital library has been constructed also by Chu at al. [30]. One should note that the term 'medical digital library' is also often used to denote digital libraries with a collection of medical publications like, for example, MeDLib@NIC [31], SUMS Medical Digital Library [32] or a digital library at Hurvey Cushing/John Hay Whitney Medical Library [33]. This type of a digital collection of medical publications is built within the "Telemedycyna Wielkopolska" environment with the use of the dLibra digital library framework [34].

The Medical Digital Library that we are working on is an example of a health scenario supported by the grid technology. When looking at the health scenarios on the grid one can distinguish four major classes of medical applications: clinical, simulation, pharmaceutical and bio-informatic. "Telemedycyna Wielkopolska" is an example of a system providing clinical telemedicine. In this class important research problems include management and integration of distributed medical data [35, 36], deploying medical image analysis on the grid [37, 38, 39], collaborative visualization of medical data [40] and enabling clinical decision support on the grid [41]. A problem close to our work on storing medical images in the grid-based Data Management System is discussed in [42]. Simulation applications are deployed on GEMSS Grid [43] and GAMA [44]. An example of a pharmaceutical grid scenario can be found in [45]. Bio-informatic grid applications are widely designed around the world, for example within the Biogrid project [46].

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