A Middleware Grid for Storing, Retrieving and Processing DICOM Medical Images

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Abstract. The work described in this paper presents a middleware (MW) that has been developed using Grid technologies oriented to the management of digital medical images in DICOM format. The main objective of this MW is to provide transparent access to the resources concerning medical imaging, shared within virtual organizations (VOs). Resources are shared securely and efficiently in all stages, comprising storing, retrieval and processing. An OGSA-based architecture and an implementation based on the OGSI infrastructure and the Globus 3 toolkit are presented in the article. Three concrete resources have been implemented on top of this architecture for delivering three basic services: Storing of DICOM images; Transferring using JPEG2000 compression to send and receive; and Volume rendering to obtain 3D projected images.

1 Introduction

The popularisation of digital, digitised and film-less radiology has increased the need for computer-based applications that could store and process the medical information at both patient and population level. Currently, most European hospital store and browse images in digital local databases. However, procedures, protocols, formats and applications vary quite much among centres, which make interoperability difficult.

This work aims at the design and development of a Middleware (MW) Grid for managing DICOM [1] image studies. Management involves transferring, storing and processing images on high performance computers HPC [2]. The main objective has not been to implement a specific solution for accessing DICOM images, efficiently solved by commercial products, but to create an environment to enable the secure sharing of information and resources across different organisations. Control on the independent resources is preserved, and the Grid architecture provides a secure and efficient mean to share the computer resources and the part of the data that each centre authorises each users to access to. Access rights are individually granted to ensure the control in the privacy of data. Three specific resources are implemented on top of the architecture oriented to three basic tasks: storing and retrieval of DICOM images, Volume Rendering of tomographic studies [3] and image transferring using JPEG2000 [4][5] encoding. These services implemented act both as demonstrators of the viability of the architecture, and as basic components to develop higher-level applications.

The objective of the MW is to set up an environment in which software developers can use transparently distributed resources in medical organizations. Neither software developers nor users should care about the location of resources. Software developers will only have to declare requirements (memory, performance, Quality of Service and the like) and the environment will either decide or offer the information to discover and use the most appropriate resources. Users will only care about services, which will be executed on the most suitable computer node and the best source of data available. As an example, if a 3D projection of a study is required, a Resource Broker will select the most suitable computer resource offering that service, considering the size of the study, the location of the database storing it and other performance factors. This logic idealization of the resources abstracts the physics features of devices and platforms, constructing the high-level concept of an environment of logical resources (services) rather than physical computers interconnected. The resources implemented can be replicated in different VOs, either within hospitals, across different centres of a health-care network or even at inter-organisational level.

The system is currently on development and has not been used in production. Further steps are considering the development of a pilot in the Valencian Region in Spain.

The article comprises 4 sections. This section has covered the introduction and objectives of the work. Section 2 describes the state-of-the-art in Grid technology with a brief description of basic concepts on the problems of managing radiological image files medical imaging. Section 3 exposes the architecture implemented and the three basic components developed. Finally, section 4 describes the conclusions.

2. The State of the Art

A wide range of technologies studied for the development of this MW Grid are presented next. The reasons that lead to the choice of OGSA and OGSI are presented at the end of this section. Prior to the analysis of the technologies available for distributed components, a brief summary about the issues on medical imaging processing that concerns the environment is provided.

2.1 Medical Imaging Storage and Processing

Despite of the diversity of sources for digital medical imaging (CR, Digital X-Ray detectors, MRI, CT, PET, SPECT, Ultrasound, etc.) all modalities are usually encoded in DICOM format. DICOM stands for Digital Image and Communications in Medicine and it is a format world-wide accepted by medical users and vendors of medical image acquisition devices. The consolidation of DICOM has leveraged the development of computer applications for the processing of medical image studies, and has eased the set up of collaborative environments, where medical images, preserving their clinical value, can be understood by different computer applications.

Medical images have grown on size and complexity, overtaking the capabilities of conventional computers and demanding high-performance resources. HPC has been traditionally expensive until the consolidation of commodity-based clusters. Many tasks regarding medical imaging (such as volumetric registration, large-scale segmentation and projection) require HPC resources for delivering acceptable performance. Sharing computer resources within and across centres would increase the efficiency on the use of the resources leveraging affordability.

Second critical resource in medical image management is network bandwidth. Storage is a scalable resource that can grow steadily without requiring exponential investment. Network bandwidth simply cannot. Medical image compression is a sensitive subject, since high compression ratios cannot be achieved with loss-less formats. Lossy formats are not clinically valid. Moreover, most image compression techniques have been designed for up to 8-bit depth colour channels. Medical images are usually gray-scale with deeper bit resolutions. JPEG2000 is a very interesting alternative that provides an efficient performance on loss-less compression of gray-scale 12/16-bit depth medical images. Moreover, JPEG2000 encoding enables the progressive transmission of different frequency fragments, providing a way to show significant information in the short time, before images are completely downloaded.

2.2 Current Technologies for Distributed Components

The consolidation of Internet as a main infrastructure for the integration of information opened the door to a new way for interoperating through Internet protocols (http, https, etc …). Pioneer web services started using Web Interface Definition Language (WIDL). The evolution of WIDL leaded to Simple Object Access Protocol (SOAP), which has support for message-oriented as well as procedural approaches. SOAP provides a simple and lightweight mechanism for exchanging structured and typed information between peers in a decentralized, distributed environment using XML [11]. Last evolution in Web Services is the use of Web Services Description Language (WSDL). It is a simple way for service providers to describe the basic format of requests to their systems regardless of the underlying protocol or encoding.

However, all these technologies have been developed considering mainly interoperability, rather than High Performance Computing (HPC). Problems relevant to HPC such as load balancing, communication costs, scalability, process mapping or data reutilization have not addressed. Several approaches [2] treat the HPC components as black boxes. More complex approaches [6][7] extend the syntax and semantics of CORBA (Common Object Request Broker Access) and similar ORB (Object Request Broker) technologies to deal with data distribution and process mapping.

But the take up of HPC on the Internet has actually arrived with the Grid. As defined in [8], a Grid provides an abstraction for resource sharing and collaboration across multiple administrative domains. Resources are physical (hardware), informational (data), capabilities (software) and frameworks (Grid middleware).

The key concept of Grid is the Virtual Organization (VO). A VO [9] refers to a temporary or permanent coalition of geographically dispersed individuals, groups or organizational units (belonging or not to the same physical corporation) that pool resources, capabilities and information to achieve a common objective.

The VO concept is the main difference among Grid and many other similar technologies. High throughput, High Performance Computing (HPC) and Distribute Databases are usually linked to Grid. High throughput applications can be executed locally in computing farms up to a scale only limited by the resources, not involving cooperation. HPC is more efficient on supercomputers or clusters than in Grid due to the overhead of encryption and the physical latencies of geographically distributed computers. Access to distributed data is efficiently provided by commercial database software packages. Grid is justified when access rights policies must be preserved at each site, without compromising the autonomy of the centres.

Grid technologies have evolved from distributed architectures. Recent trends on Grid are being directing towards Web service-like protocols. Open Grid Services Architecture (OGSA) and Open Grid Services Infrastructure (OGSI) represents an evolution towards a Grid system architecture based on Web services concepts and technologies. OGSI defines uniform exposed service semantics (the Grid service); defines standard mechanisms for creating, naming, and discovering transient Grid service instances; provides location transparency and multiple protocol bindings for service instances; and supports integration with underlying native platform facilities. The OGSI also defines, in terms of WSDL, the mechanisms required for creating and composing sophisticated distributed systems, including lifetime management, change management and notification. However, current trends will substitute OGSI by an infrastructure definition based on Web Service Resource Framework (WSRF) [10].

3 Mw Architecture Definition

This section describes the architecture developed for the MW Grid oriented to DICOM image management. The architecture defined comprises three layers: Core MW layer; Communication layer; and MW layer.

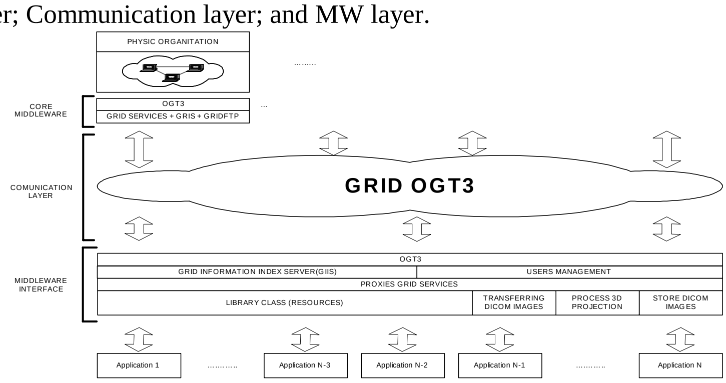

Fig. 1. General structure of the architecture and the interaction between layers.

3.1. Layers of the Architecture

Core Middleware Layer

This layer is the lowest-level one. It deals with the specificities of the hardware and the underlying operating system. This layer provides a transparent way to manage the physical resources of the Grid across logic resources. The logic resources defined in this layer are made available through a Grid Service interface [10]. Since the underlying Grid middleware used is Globus 3.0 [10], services are implemented in Java. Grid interfaces are defined using (Grid Web Services Description Language) GWSDL [10] a definition language very similar to WSDL. Actually, it is forecasted that GWSDL will be substituted by WSDL 1.2 in the short future. The GWSDL enables the discovering of resources and the access to them through SOAP protocol.

Globus 3.0 provides the Grid with the Monitoring and Discovering Service (MDS) [10]. The MDS enable to publish resources and query their status. The MDS requires each computer to include a Grid Resource Information Server (GRIS) [12] that informs about the actual status of the resource. This status is defined using XML documents that are updated online on the Grid Information Index Server (GIIS).

File transfer is performed through Grid ftp [12]. A Grid ftp Server is installed on the storage elements providing the security and privacy protection of data and reliable communications. A specific component for medical images (providing encoding progressive transmission and encryption) developed in the MW Layer use this basic protocol. This layer comprises the basic Grid components of Globus and the components developed in this work for the integration of the medical imaging devices of the Grid (data repositories, scanning devices, processing engines, etc).

Communication Layer

The communication layer acts as a link between the Middleware Layer (the closest to the user) and the Core Mw (the closest to the physical devices). Communication is provided through SOAP protocol, supported by other lower-level protocols (https, http, ftps, ftp etc). GridFtp protocol is used to transfer large data volumes between Server GridFtp of Core MW Layer and the MW Layer. Communication is performed by the DICOM image transferring component described in subsection 3.3.

Complex data structures to be transferred are defined in XML, thus easing the integration between the layers. The MW layer is thus language-independent and can be implemented in any programming language that can interact with WSDL and XML. Current version is in Java, although porting to other languages is planned.

MiddleWare Layer

The MW Layer is the interface to the applications. It uses the fabric resources through the Communication Layer. Resources available in the Core MW layer are encapsulated into objects which can be used by the developers as components for their applications. An object-oriented software library has been implemented to support high-level methods and attributes.

3.2. Grid Security

Data security in the Grid is based in GSI (Grid Security Infrastructure). Primary motivations behind the GSI are:

- The need for secure communication (authenticated and confidential) between entities of a Grid.
- The need to support security across organizational boundaries, thus preventing a centrally-managed security system.
- The need to support "single sign-on" for users of the Grid, including delegation of credentials for computations involved multiple resources and/or sites.

GSI is based on public key encryption, X.509 certificates, and the Secure Sockets Layer (SSL) communication protocol. Extensions to these standards have been added for single sign-on and delegation. The Globus Toolkit's implementation of the GSI adheres to the Generic Security Service API (GSS-API), which is a standard API for security systems promoted by the Internet Engineering Task Force (IETF).

However data security in Health Grids must be one level up. Local storage is by definition secure and moreover, Grid philosophy aims at preserving the procedures and methods used by Grid centres to manage their resources. However, confidentially transferring data across the different sites must be guaranteed. Neither other users nor the administrators of the local resources involved in the Grid should be able to read data temporally transferred to a local resource by a Grid user. Thus automatic encryption and decryption of data must be provided.

Certificates of authenticated users can solve this problem. Public keys are used to encrypt data when copied from a DICOM storage repository to a local disk in the Grid. Services accessing the data use the private keys of the users to decrypt the information when required. This process is transparent to the user, the encryption is unique and privacy is not compromised.

3.3. Resources Implemented

According to the design of the architecture described in the previous sections, three resources have been defined on the MW layer: A DICOM Storage Element, providing browsing, querying and storing; a Volume Rendering Element [3], providing 3D projection of medical studies; and an Image Transfer resource, providing the means for JPEG2000 image compression and progressive transfer. The resources have been developed using Globus Toolkit version 3.0.

DICOM Storage Element

The DICOM Storage Resource is the interface for the Grid to DICOM repositories (PACS or Workstations connected to Scanning Devices). It manages the browsing, downloading and uploading of DICOM studies to and from the Grid. The service comprises several distributed components. Local DICOM repositories are managed by a component developed in the Core MW layer. This component is system-dependent and currently supports DICOM communication protocols and standard file system access. This resource uses the Grid Ftp service to prepare the transferences of data to the clients and hides the particularities of each site, providing a uniform and transparent access to data.

A DICOM management software library has been developed to support the basic tasks regarding to format encoding and decoding and integrates JPEG2000 compression to support the Image Transfer Resource.

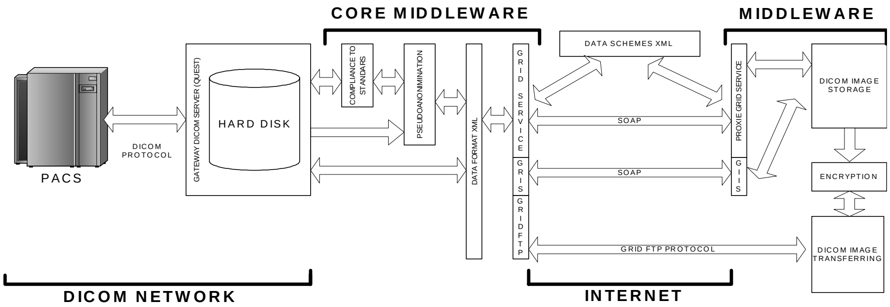

Fig. 2. Scheme of the DICOM Storage Element and the DICOM Image Transferring

Volume Rendering

This is a component that demonstrates the possibilities of Grid Computing. It provides a projection engine to obtain 3D projections of tomographic medical studies.

The Core MW Layer comprises a set of services providing the necessary interaction between the DICOM Storage and the processing resources in the MW Layer. The service enables the user to select the study, the projection method and the resource to execute the processing, and automatically receive the results on the client side.

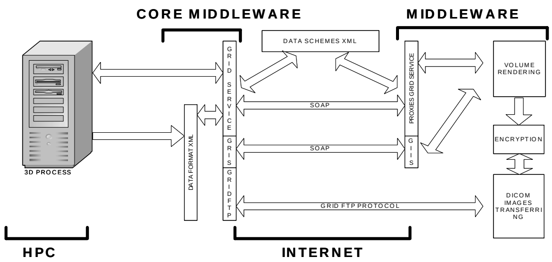

Fig. 3. Structure of the Volume Rendering Resource and its interaction with the DICOM Image Transferring Resource.

Transferring of Images

This component of the MW Layer deals with the management of the progressive downloading of images at different levels of resolution. It uses the JPEG2000 encoding provided in the Core MW Layer by the DICOM Storage Resource and performs the transmission into blocks that can be presented on the user's screen. This progressive transmission reduces the unproductive waiting time of the user and ensures that a loss-less clinically-valuable image will be always available if the users wait for the transmission to be completed.

4. Transfer and compression Results

For the testing of the MW components developed, two different test cases have been proposed: A dataset of 41 standard CT images (512x512 and 12 bits) and an X-Ray chest image (1955x1841 and 12 bits). Communications consider 10 Mbps Ethernet.
GridFtp protocol is oriented to the transmission of large data files on broad band connections. In the case of medical images, neither the size of the individual files is that large nor is the bandwidth of the communication links unlimited. Thus it is important to reduce communication costs. Compression on the image files is necessary, but compression in medical images imposes several constraints. Lossless compression is compulsory and progressive transmission is highly desirable. The compression ratio of the JPEG2000 format is better than other standard lossless compression formats. Classical medical image compression with JPEG or TIFF cannot deal with raw 12-bit DICOM images (required for diagnosis). Rar or ZIP formats present worse compression ratios. Moreover, JPEG2000 compression enables the progressive encoding of different levels of resolution. Considering an acceptable error ratio of 2%, the compression ratio of JPEG2000 could reach a factor above 8. As an example, figure 4 shows the evolution of the relative error depending of number of layers (levels of resolution) for the test-case image CT1 (512 x512x12Bits).
The overhead on the use of a Grid Service is small when transferring large DICOM images. However, and since communication cost depends strongly on the bandwidth of the lines, it is more important to compare the relation of the Grid Service overhead and the compressing / uncompressing computing time. Figure 5 shows the relation among these factors. In small images (a standard CT slice), the overhead of the grid service is even larger than the rest of the processes (57,36 %). In larger studies (a chest X-Ray or a few tens of CT slices), this delay is much more reduced (18,62%).

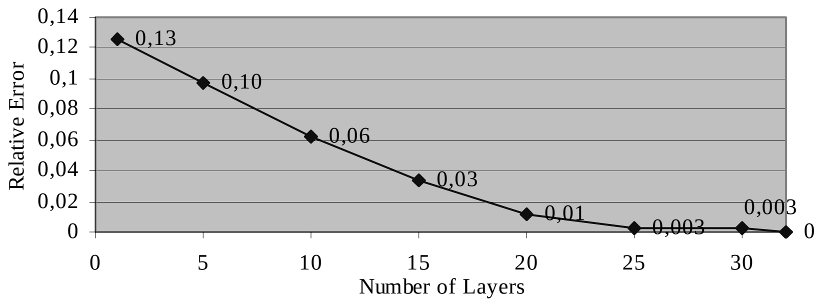

Fig. 4. Evolution of the relative error with respect to the original pixels of a JPEG2000 compressed image. Error is reduced as more layers are included, reaching a ratio below 2% for 20 layers (25% of the total compressed image).

Figure 6 shows the evolution in time and size (the latter in percentage with respect the total size) in the progressive downloading of the CT1 test image. The vertical line depicts the time-stamp in which the relative error decreases below 2%. Transferring time is longer using progressive transmission.

	Total time	%Time Compress	%Time Decompress	%Time Overhead
CHEST	20234	28,44	30,22	18,62
CT – 1	2610	12,11	26,21	57,36

Fig. 5. Total transferring time and the percentage dedicated in each part.

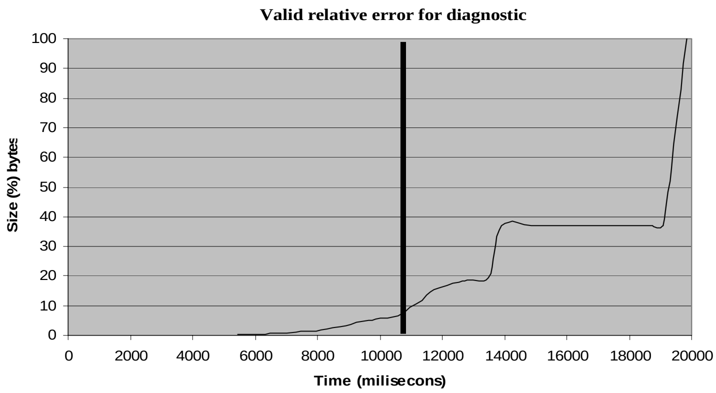

Fig. 6. Evolution of the downloading of an image with progressive transmission. The vertical line shows the instant in which relative error goes below 2%.

5. Conclusions and Future Works

The Grid Structure defined provides both an abstraction of the particularities of different centres, providing a uniform and wide view of the resources available to a community and also abstracts the users and developers from many of the particularities of the Grid Technology. Access is ubiquitous and processing is very flexible, reducing the burden of explicitly defining the transferring of data to and from the repositories, the processing components and the user and guarantees the confidentiality by providing an automated encryption.

Three components (DICOM Storage, Volume Rendering and Image Transfer Resource) have been developed to demonstrate the basic functionality of the architecture, which is an open frame for new components to be implemented and deployed.

Future work is planned in the following lines:

- Migration of the MW components to other languages for better performance.
- Develop high-level applications using the components. Applications under study are oriented to image diagnosis and content-based searching.
- Define the collaboration policies for the VO's in the architecture to ease the collaborative use of resources.
- Improve the Resource Broker component for high throughput applications and data storage.

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