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CardioGRID: a framework for the analysis of cardiological signals in GRID computing

Juan Francisco Garcia Eijo¹, Marcelo Risk¹, Francisco Prieto
Castrillo², Cesar Suarez Ortega², Maria Boton Fernandez², Alfonso
Pardo Diaz², Manuel Rubio del Solar² and Raul Ramos Pollan²

¹Laboratory of Complex Systems, Department of Computer Science, FCEyN. University of
Buenos Aires, Argentina.

²Extremadura Research Centre for Advanced Technologies. Research Centre for Energy,
Environment and Technology (CETA-CIEMAT). Trujillo, Spain.

E-mail: jfgarcia@dc.uba.ar - mrisk@dc.uba.ar

Abstract. The present paper describes the development of the CardioGRID framework into the GRID infrastructure. The core GRID services; Workload Management System (WMS), Data Management System and Grid Authentication have been implemented. Additionally, a web-based tool -the CardioGRID portal- has been developed to facilitate the user interaction with the GRID. As a result, the user is able to process the electrocardiogram (ECG) signals obtained from a portable data acquisition device and to process it on the GRID. Once the CardioGRID portal is prompted and the user identity is verified through a digital X.509 certificate, the operator may either upload new raw ECG data to the GRID Storage Elements or use already stored data. Then, subsequent analytics from these data are performed as GRID jobs and relevant medical quantities are derived through middle-ware job retrieval mechanism. In summary in this paper was described the development of a medical GRID based system, and its integration to an existing platform for Digital Repositories Infrastructure.

1. Introduction

1.1. e-Health Technologies and GRID

The group of technologies used in e-Health are mainly electronic and communications processing of medical data, in order to assist health care, such as telemedicine, health care information systems, electronic medical records and mobile devices for health care, among others [1].

Telemedicine is the use of devices and communications systems, where physiological measurements in patients are transferred using Internet, telephone, or two way digital TV systems, between the patients location to a health care facility; applications of telemedicine includes access to patients in remote locations, or simply access to patients in their home for routine control [2].

Health care information systems applies computers resources, such as devices, storage, retrieval, and programs, to implement clinical guidelines and processes. These guidelines and processes involve the architecture of medical records to manage patients information, medical decision support, standards of medical data, images and signals (HL7 and DICOM) [3].

Using mobile devices for health care -also known as mHealth- comprises the interaction of different mobile devices and technologies, such as mobile and smart phones, PDAs, combinations

of all them, together with physiological sensors to measure patients signals [4, 5].

mHealth can be thought as telemedicine as far as it is the technology which provides patients data, both from sensors and demographic data. The mHealth technology seems to be an alternative for low income countries [6] where mobile phones and services are accessible to most people by providing the last mile connection for large telemedicine networks [5].

On the other hand, distributed computing technologies (and more specifically, GRID computing) are becoming more and more popular among researchers. In this regard, the efforts of European Commission Projects, such as Enabling Grids for e-Science (EGEE) [7] or E-Science Grid Facility for Europe and Latin America (EELA-2) [8] along with the National Grid Initiatives [9] are bridging the gap between the end user and GRID.

Three main features characterize the GRID infrastructure; computing and storage power, security and collaboration. Whereas in a High Performance Computing environment (HPC), the computing power plays an essential role, it is in the possibility of collaboration where High Throughput Computing (i.e. GRID computing) finds its major strength.

GRID computing provides a powerful alternative to handle large amounts of data and processing, therefore, it has potential to be used in medical research, where is common clinical trials involving large patients databases, and physiological and genomes modeling, which needs intensive computer processing [10, 11].

1.2. Cardiological Signals

The cardiological signals such as the electrocardiogram (ECG), and the blood pressure (BP), show the electrical activity and the main mechanical effect of the heart, respectively; from the ECG signal can be derived the heart rate (HR), detected measuring the interval between adjacent R waves from the ECG [12].

The HR variability (HRV) is an indicator of the beat-to-beat modulation by the autonomic nervous system (ANS) [12, 13]. The diseases which affects the ANS, such as diabetes, leads to an impaired regulation of the heart rate, this can be detected analyzing the HR variability [13].

The length of ECG recordings varies from minutes to several hours, in the case of Holter tests the ECG is recorded during 24 hours [13]. In the Figure 1 can be observed the HR obtained from a healthy patient, during 24 hours, showing large changes the day of the test; assuming a mean heart rate of 70 beats per minute, the total number of beats can be more than 100,000 beats for 24 hours.

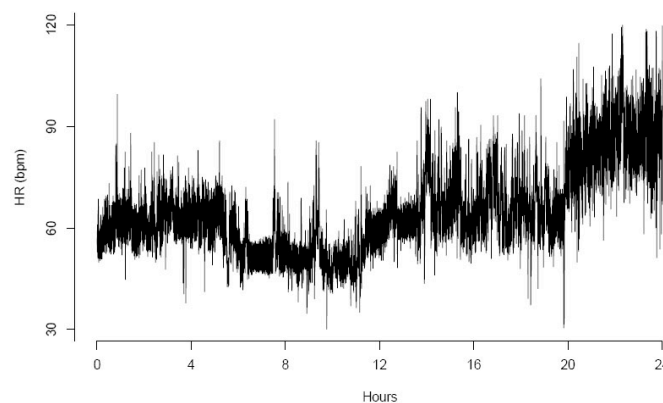


Figure 1. HR versus time for a Holter test of 24 hours.

1.3. Objectives

The CardioGRID framework objectives were the development of a mobile device for ECG and data recording, and the development of a GRID computing system for the processing of ECG, the calculation of HR, the classifications of heart beats, and both time and frequency domain of the HRV.

2. GRID Implementation for the CardioGRID Portal

2.1. The CardioGRID Framework

The CardioGrid framework comprises three basic elements, as shown in Figure 2.

- Mobile device for ECG recording and data patient entry (smart phone with ECG module),
- Web portal to transfer ECG and data from patients,
- Grid infrastructure for ECG processing.

The Portal possesses two possible use cases:

- The user, either a physician or a technician, who is in a rural zone where the patients do not have access to a full-equipped health center, through a smart phone and the ECG acquisition module obtains the ECG patients. When the user returns to a urban zone with Internet access, will be able to connect to the Portal and transfer the ECGs to process them.
- The patient ECG is stored in the PC of the user. In this case, the user, access via Internet to the portal, uploads the patient personal data and attaches the ECG that desires to process on the GRID infrastructure. Once that it was delivered the user could consult the process state, and obtain the results when it is finished.

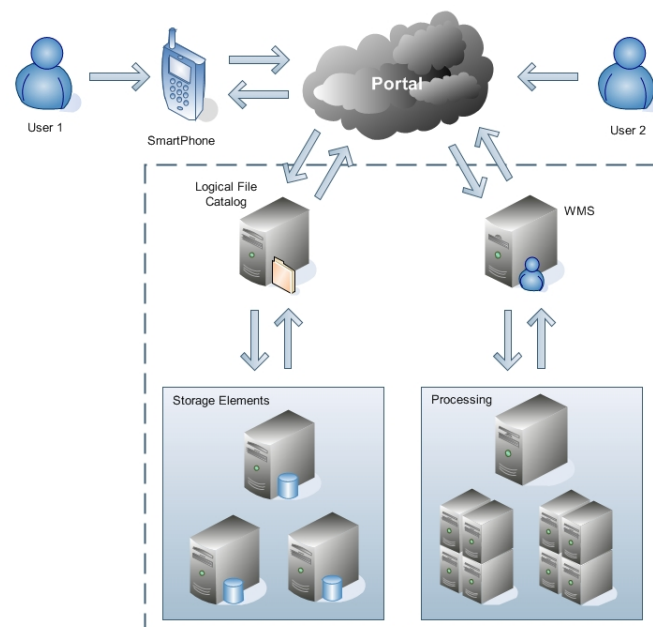


Figure 2. CardioGrid framework scheme, showing the three basic elements: mobile device using a smart phone, web portal and Grid infrastructure.

The Figure 3 shows an smart phone acquiring ECG from a patient, the connection between the ECG module and the smart phone is using bluetooth connectivity.



Figure 3. Smart phone acquiring ECG from a patient.

2.2. The ECG processing on the GRID.

Once that the user completes the patient data and attaches his ECG satisfactorily from the Portal, the ECG with file extension (.dat) is transferred via Internet to a storage element (SE) of GRID infrastructure and its physical direction is stored in a Logical File Catalog (LFC) as it is shown in Figure 4.

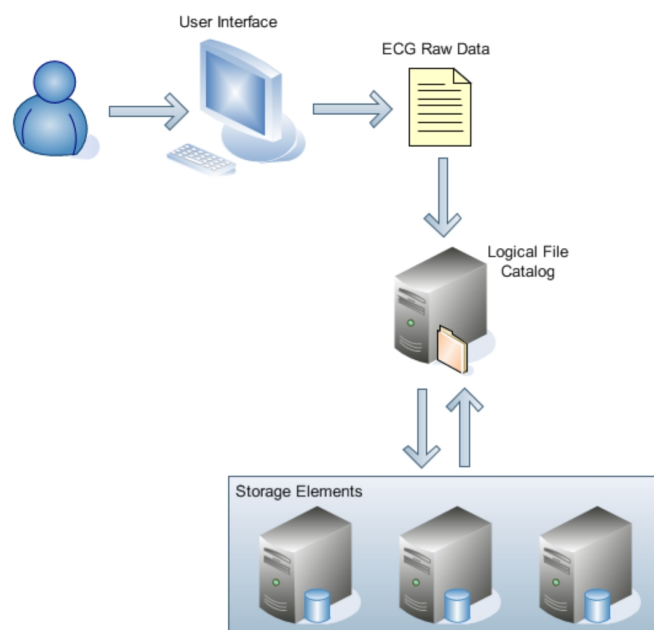


Figure 4. ECG raw data file (.dat), which is transferred to the SE of the Grid infrastructure.

Then the Workload Management System (WMS) selects an available Computing Element (CE) that adjusts to our work and sends to process the appropriate ECG. It is process using a special algorithm developed in C++ for wave detection R [13]; the transformation results are temporary stored a Worker Node (WN), as it is shown in Figure 5.

The ECG detection file (.txt) is processes with the ECG data file (.dat) in order to improve the detection rate.

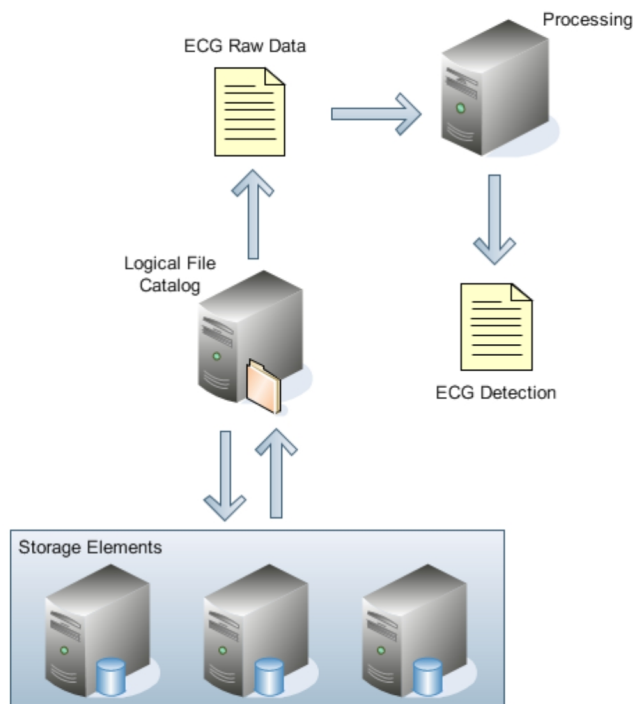


Figure 5. ECG raw data file processing. The results (.txt) is stored temporarily in the WN.

The result of this step is the RR (intervals between adjacent R waves of the ECG), as we can see in Figure 6. This file represents a HR plot versus time, this could be seen in Figure 1.

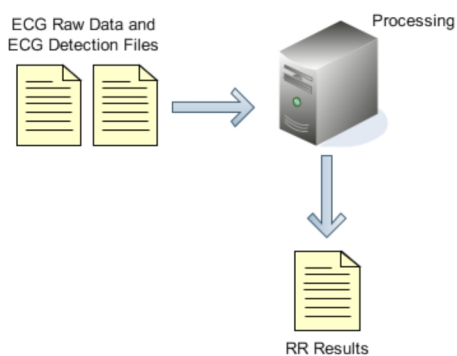


Figure 6. Combined processing of ECG Detection files and ECG Raw Data files, in order to refine the beat detection.

The last step consists in the statistic process of the interval RR file (.csv) to obtain the results file.

Once that the process on the GRID is complete, the user could choose whether to download the results to his PC or to just visualize them in the web (Figure 7).

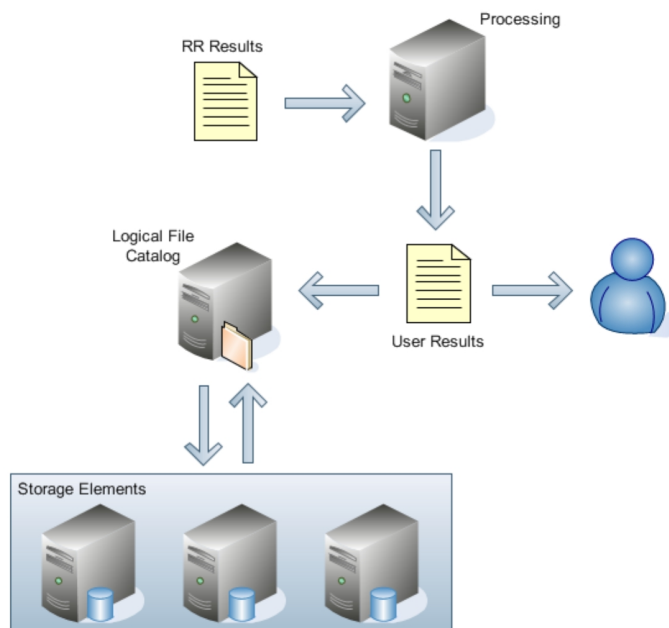


Figure 7. Statistical processing of the RR intervals file (.csv).

3. Conclusion

The present paper describes the development of a GRID based system, suited for an specific medical application; this kind of applications requires secured access, confidentiality of data, data replication, and fault tolerance. All of the above specifications can be filled using a GRID computing based infrastructure.

In the case of secured access, users can benefit using GRID certificates, based on the X.509 specification.

The confidentiality of the patients data is addressed by the use of encrypted transfers, in this project we were the first using the secure copy service implemented in gLite.

This mechanism allows several groups to work on the same project, and more importantly to share resources across the Grid securely. Data replication and fault tolerance are easy to implement in a GRID infrastructure, since by definition these systems are distributed, allowing multiple copies of the data at different physical machines, and therefore increase the fault tolerance.

The benefits for users accessing via web portal, is a very easy access to the power of the Grid, since they dont need any Grid computing knowledge.

The algorithms implemented in this paper dont need a high power of processing, however the advantage using Grid computing is the distribution of several simultaneous processes along the Grid, instead a single computer to process all of them in a queue.

More advanced algorithms, such as neural networks among others, could be easily added to a Grid based infrastructure, and rapidly available to all users.

4. Future Work

The work presented in this paper settled the basis for the development of a GRID-based repository framework for ECG analysis.

Basically, a Digital Repositories Infrastructure (DRI) constitutes a platform to host and manipulate arbitrary data structures on the GRID [14]. In this regard, the CardioGRID framework can benefit from the advantages of a full GRID-based tool which exploits the

sharing and computational capabilities of the GRID. Hence, new communities could deploy ECG repositories on the DRI engine, perform sophisticated analyses on them and share results amongst researchers.

Here, the main architecture layers are shown:

- A user interface (UI) allowing users to navigate into federated data space.
- Grid storage elements to hold the main bulk of the digitalized data.
- A federated database for storing meta information about the data stored in the grid.

In this regard, the ECG work shown in this article could be adapted to a DRI repository by defining a ECG data model. Then, in an automatic way, the ECG data and its processing mechanisms benefit directly from the Grid Features through the DRI framework.

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