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A cloud solution for medical image processing

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Abstract
The rapid growth in the use of Electronic Health Records across the globe along with the rich mix of multimedia held within an EHR combined with the increasing level of detail due to advances in diagnostic medical imaging means increasing amounts of data can be stored for each patient. Also lack of image processing and analysis tools for handling the large image datasets has compromised researchers and practitioner's outcome. Migrating medical imaging applications and data to the Cloud can allow healthcare organizations to realize significant cost savings relating to hardware, software, buildings, power and staff, in addition to greater scalability, higher performance and resilience. This paper reviews medical image processing and its challenges, states cloud computing and cloud computing benefits due to medical image processing. Also, this paper introduces tools and methods for medical images processing using the cloud. Finally a method is provided for medical images processing based on Eucalyptus cloud infrastructure with image processing software "ImageJ" and using improved genetic algorithm for the allocation and distribution of resources. Based on conducted simulations and experimental results, the proposed method brings high scalability, simplicity, flexibility and fully customizability in addition to 40% cost reduction and twice increase in speed.
Keywords: Medical Image Processing, Cloud Computing, Eucalyptus, ImageJ, Improved Genetic Algorithm.

I. Introduction

The rapid growth in the use of Electronic Health Records (EHR) across the globe along with the rich mix of multimedia held within an EHR combined with the increasing level of detail due to advances in diagnostic medical imaging means increasing amounts of data can be stored for each patient [8][9]. In a scenario where a consultant may view and process medical images remotely for the purpose of producing a diagnosis it may be necessary to move large data sets across the network for processing to take place [10]. Moving such data sets has the potential to introduce undesirable latency and also degrade application performance to an unacceptable level, causing service level agreement (SLA) violations and degrading network performance for other users of the same infrastructure.

With the advanced imaging technologies such as synchrotron based X-Ray microscopy and micro-spectroscopy, and computed tomography, research scientists can directly acquire the images of sub-cellular structures and have a new dynamic view of life. These imaging facilities have a broad user base and have attracted lots of scientists and engineers from universities, institutes and industries locally and even overseas carrying out their experiments and R&D activities. Therefore, reconstructing, pre-processing and quantifying the large image datasets are in high demand. Medical image analysis often involves interleaving numerous tools from heterogeneous sources, which brings about the problems of data compatibility, file formats, and interface with multi-processing computing environments. However, the lack of image processing and analysis tools for handling the large image datasets has compromised their research outcome [2].

Cloud Computing has come to the fore as a new model of computing service delivery as a utility over the Internet. Virtualization technology [11] lying at the heart of the Cloud allows greater utilization of physical and virtual resources. Depending on the resources available physical hosts or nodes on the Cloud can host numerous virtual machines, which in turn can host applications and data. Migrating medical imaging applications and data to the Cloud can allow healthcare organizations to realize significant cost savings relating to hardware, software, buildings, power and staff, in addition to greater scalability, higher performance and resilience [12][13].

This paper reviews medical image processing and its challenges, states cloud computing and cloud computing benefits due to medical image processing. Also, this paper introduces tools and methods for medical images processing using the cloud. Finally a method is provided for medical images processing based on Eucalyptus cloud infrastructure with ImageJ open source java-based program as image processing program and using improved genetic algorithm to optimize the combined placement of image processing algorithms (as Virtual Machines - VMs) and image data sets on compute and storage nodes respectively.

II. Medical Image Processing and its Challenges

Medical image data, which are collected with medical imaging devices, such as X- ray devices, MRI devices, Ultrasound devices, Positron Emission Tomography (PET) devices or CT devices in the diagnostic imaging departments of medical institutions, are used for an image interpretation process called "reading" or "diagnostic reading." After an image interpretation report is generated from the medical image data, the image interpretation report, possibly accompanied by representative images or representations of the examination, are sent to the requesting physicians. Today, these image interpretation reports are usually digitized, stored, managed and distributed in plain text in a Radiology Information System (RIS) with accompanying representative images and the original examination stored in a Picture Archiving Communication System (PACS) which is often integrated with the RIS [2].

Typically, prior to the interpretation or reading, medical images may be processed or rendered using a variety of imaging processing or rendering techniques. Recent developments in multi-detector computed tomography (MDCT) scanners and other scanning modalities provide higher spatial and temporal resolutions than the previous-generation scanners. Advanced image processing was first performed using computer workstations. However, there are several limitations to a workstation-based advanced image processing system. The hardware and software involved with these systems are expensive, and require complicated and time consuming installations. Because the workstation can only reside in one location, users must physically go to the workstation to use the advanced image processing software and tools. Also, only one person can use the workstation at a time [2].

Some have improved on this system by converting the workstation-based advanced image processing system to a client- server-based system. These systems offer some improvements over the workstation-based systems in that a user can use the client remotely, meaning the user does not have to be physically located near the server, but can use his/her laptop or computer elsewhere to use the software and tools for advanced image processing. Also, more than one client can be used with a given server at one time. This means that more than one user can simultaneously and remotely use the software that is installed on one server. The computational power of the software in a client-server-based system is distributed between the server and the client. In a "thin client" system, the majority of the computational capabilities exist at the server. In a "thick client" system, more of the computational capabilities, and possibly data, exist on the client [2].

The hardware software installation and maintenance costs and complexity of a client-server based system are still drawbacks. Also, there can be limitations on the number of simultaneous users that can be accommodated. Hardware and software must still be installed and maintained. Generally the information technology (IT) department of the center which purchased the system must be heavily involved, which can strain resources and complicate the installation and maintenance process [2].

III. Cloud-Base Medical Image Processing

A cloud system refers to a system which is server-based, and in which the software clients are very thin - possibly just a web browser, a web browser with a plug-in, or a mobile or phone application, etc. The server or server cluster in the cloud system is very powerful computationally and can support several users simultaneously. The server may reside anywhere and can be managed by a third party so that the users of the software in the cloud system do not need to concern themselves with software and hardware installation and maintenance [2].

A cloud server receives over a network a request for accessing medical image data from a first user, where the cloud server provides image processing services to a plurality of users using a plurality of image processing tools provided by the cloud server. The cloud server determines user privileges of the users for accessing the medical image data, where the user privileges are related to the medical image data. The medical image data was captured by a medical imaging device and stored in a storage associated with the cloud server. The availability of the image processing tools is limited to the user to process the medical image data based on the user privileges. Cloud Computing uses a ‘pay as you go’ pricing model whereby users only pay for the amount of resources they consume, e.g., storage, memory, CPU, bandwidth. Additional resources can also be provisioned in an on-demand fashion to allow scaling with application and user demand [1].

3.1 Benefits of medical image processing in the cloud

Cloud computing provides computation, software, data access, and storage services that do not require end-user knowledge of the physical location and configuration of the system that delivers the services. Cloud computing providers deliver applications via the Internet, which are accessed from Web browsers, desktop and mobile apps, while the business software and data are stored on servers at a remote location. Cloud application services deliver software as a service over the Internet, eliminating the need to install and run the application on the customer's own computers and simplifying maintenance and support [2].

A cloud system also allows for dynamic provisioning. This allows lower costs and removes the need for the individual sites to have to manage the asset. The cloud servers can handle backups and redundancies and security so the users do not have to worry about these issues. The users can have access to all and the newest clinical software without having to install the same. Tools and software are upgraded (automatically or otherwise) at the servers to the latest versions [2].

A cloud server, also referred to as an image processing server, has the capability of processing one or more medical images to allow multiple participants to view and process the images either independently or in a collaborated manner or conferencing environment. Different participants may participate in different stages of a discussion session or a workflow process of the images. Dependent upon the privileges associated with their roles (e.g., doctors, insurance agents, patients, or third party data analysts or researchers), different participants may be limited to access only a portion of information relating to the images or a subset of the processing tools without compromising the privacy of the patients associated with the images [2].

The browser/client/mobile application standards allow easier integration with an electronic health record. The integration can be done as seamless as possible, so one does not have to open separate applications or repeatedly enter login information. Integration may be based on patient ID, or other common parameter which automatically links different types of records [2].

As described above, advanced image processing in the cloud model allows users from anywhere to access and contribute to the same case or cases. An extension of these concepts is a clinical or research trial. In a clinical or research trial, patient data from different geographical locations are grouped and tracked over time to identify trends. The cloud model allows for doctors or other participants all over the world to participate. It controls what tools are used and how and by whom. It allows data to be aggregated because all data is stored on the same server or cluster of servers. It allows easier training for the doctors and technicians and others involved in analyzing data for clinical trial or research study. The cloud-based model easily supports the role of auditor/quality control person. It monitors data trends as trial is progressing and performs data analysis at the end of a trial/study and also during a trial/study. It also integrates with data analysis software, giving access to third parties such as a sponsor or the FDA, and controls access and level of access.

IV. Related works

In this section, we present some methods and tools that have been proposed for cloud-base medical image processing.

Bednarz et al. [3] proposed Cloud Based Image Analysis and Processing Toolbox being carried out by CSIRO, is to run on the Australian National eResearch Collaboration Tools and Resources (NeCTAR) cloud infrastructure and is designed to give access to biomedical image processing and analysis services to Australian researchers via remotely accessible user interfaces. The toolbox is based on software packages and libraries developed over the last 10-15 years by CSIRO scientists and software engineers: (a) HCA-Vision: developed for automating the process of quantifying cell features in microscopy images; (b) MILXView: a 3D medical imaging analysis and visualization platform increasingly popular with researchers and medical specialists working with MRI, PET and other types of medical images and (c) X-TRACT: developed for advanced X-ray image analysis and Computed Tomography. By providing user-friendly access to cloud computing resources and new workflow-based interfaces, our solution will enable the researchers to carry out various challenging image analysis and reconstruction tasks that are currently impossible or impractical due to the limitations of the existing interfaces and the local computer hardware. Several case studies will be presented at the conference.

The NeCTAR [25] research cloud delivers basic compute and storage capabilities as standard services over the network. Servers, storage systems and network resources are pooled and made available to handle workloads ranging from application components to high performance computing applications. The NeCTAR cloud uses the OpenStack cloud operating system which is architected to provide flexibility with no proprietary hardware or software requirements. The OpenStack cloud operating system provides three shared services, Compute, Networking and Storage. The OpenStack Compute provisions and manages large networks of virtual machines; the OpenStack Networking provides pluggable, scalable, APIdriven network and IP management services; and the OpenStack Storage provides services of object and block storage for use with servers and applications. The OpenStack dashboard provides administrators and users a graphical interface to access, provision and automate cloud based resources [3].

The image analysis and processing platform (PaaS) represents the development and runtime environment where the image analysis and processing tools are executed. The platform also provides the basic management features of the single node and leverages all the other operations on the services that it is hosting. The services include task submission, job and resource scheduling, error handling, reporting (traffic, client demands and usage), execution of the tools, operation status and progress monitoring, results returning etc. The platform encapsulates a layer of software and provides it as a service that can be used to build high level image analysis and reconstruction services [3].

The SaaS layer features three applications offered as a service on demand. A single instance of each of the image analysis packages runs on the cloud and serves multiple end users. The software packages include HCA-Vision, X-TRACT and MILXView. Due to limitation of space, the functions will be provided during poster session [3].

Figure 1 depicts more detailed software architecture of the cloud based image analysis system.

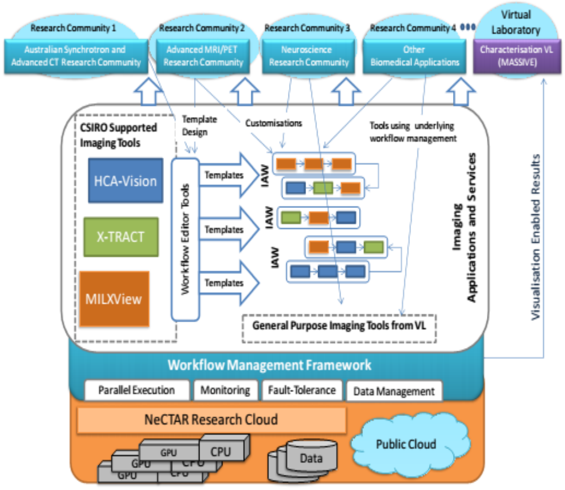

Figure 1. Software architecture of the NeCTAR system [3]

Bo Li et al. [4] integrated the JIST image processing platform with the Amazon EC2 cloud. They aim to increase the diversity of investigators who can use modern imaging processing and genetic analyses tools through integration with the widely available Amazon Elastic Compute Cloud [EC2] architecture. They have employed JIST to develop a framework for connectivity analysis, in which structural networks can be inferred with multi-modal characterization of the tissues through which estimated tracts pass.

Java Image Science Toolkit (JIST) combines a solution for the interactive processing of individual datasets with an efficient large-scale batch processing infrastructure. The JIST image processing platform integrated with the Amazon EC2 cloud. Image processing tools can be accessed through JIST modules by using the Pipeline Layout Tool, including the MIPAV scripting system and algorithms. The Plug-In Selector is a MIPAV plug-in that provides a GUI for the user to select and execute JIST tools as (regular) MIPAV plug-ins. The Process Manager manages execution of processing tasks in a multi-processor computing environment or through the Distributed Resource Management Application API (DRMAA), which supports processing grids. Developers can use the API for its image analysis functionality and then encapsulate their algorithm in a JIST processing algorithm so that it will be automatically recognized by the pipeline environment. Hundreds of modules are currently available for image input/output, manipulation, segmentation, and registration [4].

The Java Image Science Toolkit (JIST) addresses key challenges by ensuring module interoperability, providing graphical user interfaces, and batch processing tools. Work is underway to integrate JIST with the SOLAR-Eclipse imaging-genetics package. Medical image processing involving large multi-modal datasets and imaging genetics data require management of huge amount of data and necessitates high-performance computing facilities. JIST allows external algorithms with a CLI to be wrapped as JIST modules and JIST automatically presents a CLI for all native modules [4].

Chiang et al. [20] describes how to construct and develop a cloud service for medical image processing based on the service-oriented architecture (SOA), and implements hand X-ray imaging module, for example. SOA architecture is a model consists of different standard components of web services technology. The reason for using this architecture is that it can construct a flexible, reusable, interoperable with integrated interface for internal and external communication of the cloud service. Such as cloud internal applications, web applications and user related communication to achieve the goal of software as a service. We achieve the resources integration of SOA and image processing software “ImageJ” in order to solve the various technical limitations and the communication problems between the distributed techniques. ImageJ is widely used in the field of diagnostic medical imaging with a variety of image processing and analysis, and thus the performance is enhanced for our implementation of service-oriented model in cloud on image processing functions. This paper analyzes the SOA architecture in remote communications, security and development program based on the multi-layer approach. Furthermore, we implement a specific cloud service to show that improvement on the programming techniques and steps for web service access.

They have some improvements in images processing and accessing time of some existing programs or procedures for hand radiography, which need manual handling. In addition to this study for hand radiography, other medical images processing modules and be applied to expand the capabilities of the system in the future. Moreover, this system will provide the application for diagnosis and treatment in clinical through these building modules [20].

The System is implemented based on SOA technology for consideration of the consistency, security and interoperability of Web services. Such that, let Web service package all details of internal cloud. Processing and define and publish service by the simplest way. The experimental results show that program developers can focus on the development of system according to the standardization and unification through our approach. Furthermore, the maintainability and reusability are increasing [20].

V. Proposed Method

In this section we are going to propose a new method for medical images processing that using Eucalyptus as cloud infrastructure and ImageJ as image processing program and use improved genetic algorithm for the allocation and distribution of resources to reduce problems and weaknesses of existing methods. Our Proposed method architecture is shown in fig 2.

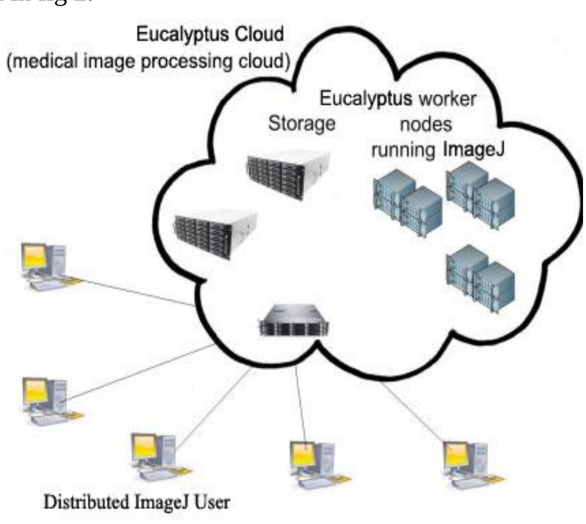

Figure 2. Proposed method architecture

A. Method cloud infrastructure

In open-source, Eucalyptus [5] is an infrastructure for cloud computing. Eucalyptus mainly includes four components. The bottommost level component is node controller, One Eucalyptus may have one or more nodes, a node controller executes on every node. The node controller queries and controls the host operating system and the hypervisor on its node. The middle-level component is cluster controller, One Eucalyptus system may have several clusters, every cluster needs a cluster controller to schedule resource in its own cluster and controller network connecting to both the nodes running node controller and the machine running. The two top-level components are node controller and storage controller (Walrus); the former offers a web interface for cloud management and EC2-compatible SOAP, and performs high-level resource scheduling and system accounting; the latter offers S3-compatible cloud storage service. Eucalyptus is a flexible tool that Users can link their programs to servers and create cluster cloud network [7]. Eucalyptus deployment shown in Figure 3.

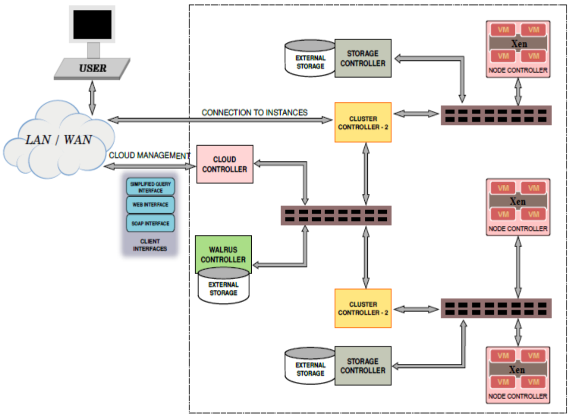

Figure 3. Deployment of Eucalyptus in method

B. Medical image processing tool of proposed method

We use ImageJ software as our image processing tool that is a java based open source for image processing and developed by the U.S. National Institutes of Health (NIH) in the public domain (Public Domain). It can be executed on Microsoft Windows, Mac OS, Mac OS X, Linux, and Sharp Zaurus PDA and other platforms. ImageJ can display, edit, analyze, process, save and print 8-bit, 16 bit, 32-bit images which support for TIFF, PNG, GIF, JPEG, BMP, DICOM, FITS and other image formats. It also supports multiple image features, that is a window in the form of a multi-threaded Cascading multiple images, parallel processing. As long as memory allows, ImageJ can open any number of image processing. In addition to the basic image manipulation, such as zoom, rotate, distort, smoothing outside, ImageJ can make the picture area and pixel statistics, spacing, angle calculation, to create histograms and profiles, the Fourier transform.

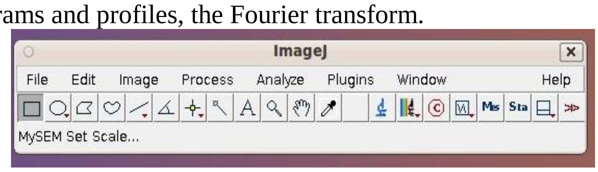

Figure 4. ImageJ Software environment in Linux

1) ImageJ Plugins

ImageJ plug-ins [21, 22] is compiled into ".class" of the java class files using the java language. Its installation is very simple, we just need to use the plug-in, which is the java class file into the ImageJ's "plugins" directory under, and then restart ImageJ, then will be in the "Plugins" menu drop-down menu appears plug-in module. It should be noted that, java class file name if the underscore "_" in the "Plugins" in the spaces will be replaced. According to implement different functions, plug-in has been divided into the following categories: image I / O processing, image analysis of the basic characteristics of various filters, graphics manipulation.

2) ImageJ Macro Language

Macros are a kind of computer language instructions [23], on behalf of the same language of a certain program or a set of instructions, when the repeated use of the segment or group instruction program can be used instead of the macro call is a convenient program design approach. Therefore, we can know that is representative of that part of a long narrative in the short program when see the name, and thus can save programming time. In our cloud service system, the user can write macros saved to a text file and upload to the cloud, just after the on-line through the web application can modify the macro, you can quickly accomplish many a series of complicated steps.

Macro is the ability to automatically produce a series of ImageJ command program. There are two ways you can create macro programs. The simplest one kind is to use ImageJ's Plugins / Macros / Record command, so that when you use ImageJ menu command, it will automatically record in a Recorder to generate macro statement, to be macro program. There is also a way to establish open Plugins / New, the pop-up dialog box, type the name of the establishment of a macro program, select the "type" to "macro", then you can edit in the pop-up list to write your own macro programming , and it is with the extension ".Txt" to save the. Provides a macro program ImageJ command to combine multiple methods, researchers can also be written according to their needs, and it’s written with object-oriented programming language JAVA and C # syntax the same.' ImageJ macro ode can be added to the toolbar, you can also add to the "plugins" menu, so its use for research and development has become more convenient and fast.

C. Proposed method resource allocation

Hybrid evolutionary algorithms, combining the best features of genetic algorithms with the best features of other evolutionary algorithms such as particle swarm optimization (PSO) [14], ant colony optimization (ACO) [15], and simulated annealing (SA) [16], have been shown to have a much shorter convergence time than purely genetic algorithm-based solutions [17]. Hybrid genetic algorithms such as the multi agent genetic algorithm [18] can offer superior performance over traditional genetic algorithms when very large scale and dynamic optimization problems are concerned. Likewise, an improved genetic algorithm (IGA) [19] has been shown to be nearly twice as fast at finding optimized solutions as a purely genetic algorithm placement solution.

As shown in Figure 4, Processing nodes and storage nodes are separated by a network containing a set of network routes between any set of nodes. A set of virtual machines containing algorithms are hosted on a set of physical processing nodes. A set of virtual machines containing data stores are hosted on a set of physical storage nodes.

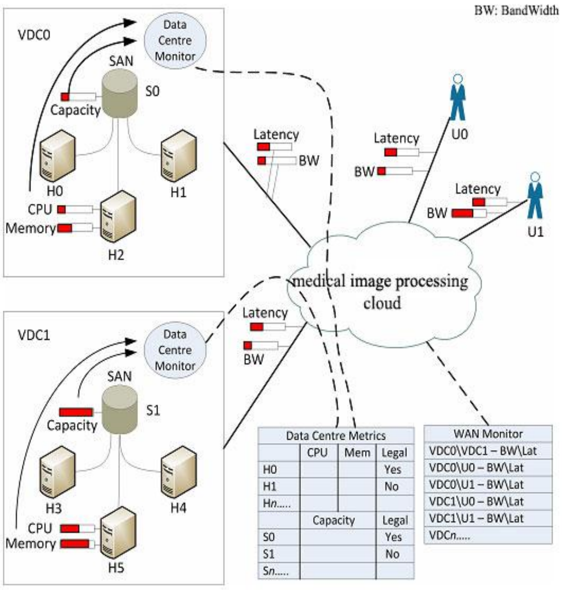

Figure 5. Architectural review of proposed method resource allocation algorithm

A set of tasks are executed on a set of processing nodes A. Each processing node has a resource capacity in terms of CPU and memory. Each task has resource requirements in terms of CPU and memory. A set of datasets are stored on a set of storage nodes. Each storage node has a resource capacity in terms of storage. Each dataset has a storage requirement.

The 'Data Centre Monitor' is responsible for monitoring the CPU and memory utilization of hosts and the storage capacity of storage area network (SAN) nodes within each Virtual Data Centre (VDC). Data Centre node metrics are gathered by distributed agents along with network health metrics collected by the 'WAN Monitor', which uses a modified version of BWPing [1-17] to monitor the end to end bandwidth and latency between all VDCs and users. The node and network health metrics are normalized and form a combined fitness score for each node, which can satisfy the physical and logical constraints. A genetic algorithm is used to find an optimized solution within the pool of viable nodes.

The most prominent advantages of proposed method are:

- A method based on open source tools for implementing cloud computing infrastructure with high scalability and fully Customizable
- Simple, flexible, and hierarchical
- Management and applications interfaces at different levels
- Reduce restrictions on CPU, memory, storage and network bandwidth with Two-fold increase in speed and 40% reduction in cost despite the high reliability
- Our method can integrate with amazon EC2 because nature of Eucalyptus as our method cloud infrastructure and Users will have access to high performance compute facilities or research clouds can use these platform in lieu of the EC2.

This characteristics make our proposed method as a high performance and optimal solution for medical image processing.

VI. Experimental results

First, the service model used for implement the definition of the service contract which defines the operation which endpoint (End Points) can offer. The main service is the ImageJ macro service layer. The service platform provides the basic macro call operation, for example, to call by name ImageJ macros services. The service contract interface ImageJSevice code snippet is shown as follows:

```
[ServiceContract(SessionMode = SessionMode.NotAllowed)]
        public interface ImageJSevice
        {  [OperationContract]
           Boolean SetImageJServerProcess(string argPath, string argParameters);
           [OperationContract]
           Boolean StartImageJProcessService(string argServiceName);
           [OperationContract]
           Boolean StopImageJProcessService(string argServiceName);
           [OperationContract]
Boolean PluginImageJProcessService(string argServiceName);}
```

In this study, we package the core of ImageJ macro service through a SOA technology, and then deployed as a service. One kind of WCF technology is used to design and development services-oriented programming framework, but also a development application of a distributed information technology [24]. Thus, the web applications and cloud services program can be very loose internal use and call for the medical images macro processing. The structure is shown in Figure 5.

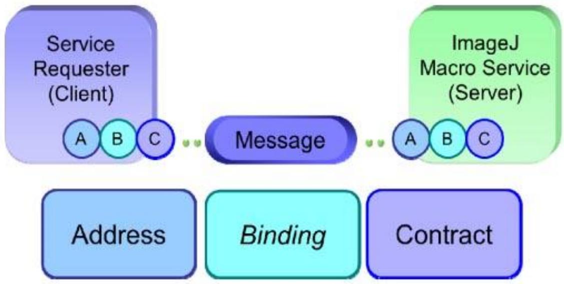

Figure 6. Structure of cloud services for contraction

Experimental results show that our system integrates the ImageJ with Web Services through cloud service based on SOA. In this paper, we integrate the image processing modules for retinal photograph into plug-in service program on the ImageJ software by service-oriented technology. When the patient image page is accessed as shown in fig 6, an ImageJ applet automatically displays the patient medical image.

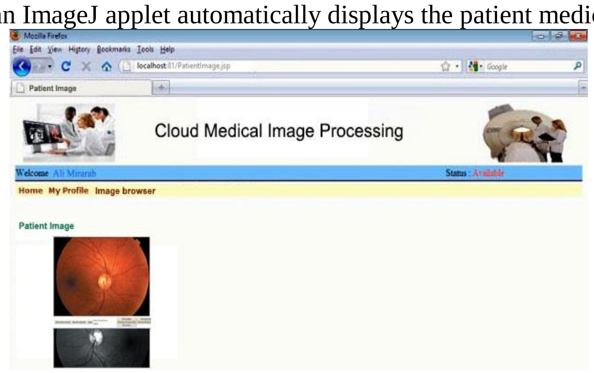

Figure 7. Patient processed image

In order to resource allocation a genetic algorithm was developed using Eclipse 7. A synthetic dataset containing values representing realistic CPU, memory, storage and network metrics for 20 physical nodes was generated. The number of physical nodes was constant at 20, whilst the number of VMs requiring placement increased in increments of 5, ranging from 5 to 75. With a maximum number of 75 VMs for placement the cost associated with genetic algorithm solution is just over 40% of the cost.

VII. Conclusions

In this paper medical image processing and its challenges reviewed and also stated cloud computing seems to be a natural solution for many problems. Also introduced tools and methods for medical images processing using the cloud. Finally a method is provided for medical images processing based on Eucalyptus cloud infrastructure with ImageJ as our image processing software. Open source nature of used infrastructure and operating system makes advantages of high scalability, simplicity, flexibility and fully customizability with management tools at all levels. In order to determine hardware placement and network connections, and also determine the method of virtualization, improved genetic algorithm has been used.

Placement of the open source Eucalyptus Infrastructure and ImageJ image processing program with improved genetic algorithm together, brings 40% cost reduction and Two-fold increase in speed.

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