Web-based Interactive Visualization of Medical Images in a Distributed System

Thiago Moraes[1], Paulo Amorim[1], Jorge Silva[1] and Helio Pedrini[2]
[1]*Division of 3D Technologies, Center for Information Technology Renato Archer, 13069-901, Campinas, SP, Brazil*
[2]*Institute of Computing, University of Campinas, 13083-852, Campinas, SP, Brazil*

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Abstract: Medical images play a crucial role in the diagnosis and treatment of diseases, since they allow the visualization of patient's anatomy in a non-invasive way. With the advances of acquisition equipments, medical images have become increasingly detailed. On the other hand, they have required more computational infrastructure in terms of processing and memory capabilities, which may not be available in hospitals and clinics with limited resources. Therefore, a convenient mechanism for providing a more effective health service is through a remote access system. In this paper, we describe and analyze a distributed system for Web-based interactive visualization of medical volumes.

1 INTRODUCTION

Data visualization (Pandey et al., 2014, Telea, 2014, Murray, 2017) is an active research field with applications in several domains of knowledge, for instance, medicine, biology, remote sensing, meteorology, entertainment, among others.

The increasing amount of acquired data has become a challenge for the traditional visualization process performed locally on a client machine, since it relies on computationally expensive resources to manipulate and display data volumes. Thus, the client machine must have sufficient processing and storage capacity.

On the other hand, remote data visualization (Engel et al., 2000, Evesque et al., 2002, Wessels et al., 2011, Blazona and Mihajlovic, 2007, Marion and Jomier, 2012) allows costly operations to be performed on a server with high processing and storage capacity, resources for providing multi-user collaboration, security mechanisms, as well as efficient version control of applications.

The high amount of data produced in the medical field requires the use of efficient image analysis techniques (Amorim et al., 2018b, Amorim et al., 2013, Moraes et al., 2018, Amorim et al., 2018a, Fazanaro et al., 2016, Ward et al., 2015, Prince and Links, 2014), which usually involve the intervention of specialists to allow greater control of the application. Examples of interactive medical applications include image segmentation, surgery simulation, virtual and augmented reality, telemedicine, computer-aided diagnosis, among others.

Advances in Web technologies have made it possible to develop collaborative visualization of medical data on the Internet, improving healthcare services. Despite the availability of hardware and software support, there are still some challenges in Web-based medical data visualization.

In this work, we present and analyze a remote system for medical data visualization on the Web. From requests sent to a server, users are able to manipulate and visualize large volumes of data quickly and directly in the Web browsing environment. Several benefits are offered to users from the proposed system. Web browser-based rendering requires no special programs to be installed on the client machine.

As main contributions of the paper, the server is responsible for performing the operations requested by the users, which dispenses the client machine from expensive requirements in terms of memory and processing. In addition, viewing results become available from any device with Internet access. The server machine is a distributed system in order to provide capabilities of performance, expansibility and reliability. The proposed solution uses only open and free packages.

This text is organized as follows. Section 2 briefly presents concepts and approaches related to the topic under investigation. Section 3 describes the method-

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ology proposed to develop a remote medical data visualization system on the Web. Experimental results are presented and evaluated in Section 4. Concluding remarks and directions for future work are outlined in Section 5.

2 BACKGROUND

Medical volume rendering consists of a set of techniques for displaying a two-dimensional (2D) of a three-dimensional data set, acquired by a medical scanner such as Magnetic Resonance Imaging (MRI) and Computed Tomography (CT).

The advances and diffusion of the Internet have leveraged the interest in developing tools for analysis and processing of medical images in an Internet browser.

Virtual Reality Modeling Language (VRML) (VRML, 2012) was one of the first proposals for modeling virtual reality in Web environments, allowing users connected to the Internet to interactively view data volumes and transmit files. However, VRML has not become a Web standard supported by the majority of the browsers, so it is necessary to install a plugin in the browser. Current leading browsers have adopted two important standards: WebGL and WebSocket.

WebGL (WebGL, 2017) is the OpenGL ES standard for browsers. It allows the creation of OpenGL contexts in browser windows and programming with the Javascript language to create three-dimensional interactive environments.

WebSocket (Fette and Melnikov, 2011) is a network protocol that allows two-way communication between client and server. Unlike Hypertext Transfer Protocol (HTTP), communication between both machines (client and server) remains active, which facilitates the transmission and development of content in real time.

Distributed systems (Tanenbaum and Van Steen, 2007) refers to an architecture in which computing nodes in a network communicate via messages to coordinate themselves in order to achieve a common goal. An interesting feature of this system is that failure of a node should not affect the entire system.

Visualization Toolkit (Schroeder et al., 2004, VTK, 2018) and Three.js (Dirksen, 2013) are some examples of libraries used to create and visualize data in a Web browser.

Publisher-Subscribe (PubSub) (Ion et al., 2010) is an asynchronous message passing model, where publishers and subscribers exchange messages without knowledge of each other. Messages are called events. In the PubSub model, subscribers signalize to the broker as interested in a particular event. The publisher sends messages (events) to the broker, which is responsible for delivering the message to the subscriber registered in the event. Redis (Carlson, 2013, RedisLab, 2018) is an open source in-memory database that can be used as broker, since it implements the PubSub model. Redis allows the broker to be distributed across multiple nodes.

Some initiatives to develop data visualization systems on the Web have been made available in the literature (Kokelj et al., 2018, Rego and Koes, 2015, Kaspar et al., 2013, Sherif et al., 2015, Marion and Jomier, 2012, Mahmoudi et al., 2010, Mwalongo et al., 2015).

3 REMOTE SYSTEM FOR MEDICAL DATA VISUALIZATION

In this section, we describe the developed remote medical data visualization system on the Web. Figure 1 illustrates the main components of the proposed remote system for medical data visualization. The system is composed of three different modules:

- *Web Server:* where the HTTP (Hypertext Transfer Protocol) (Fielding et al., 1999) and WebSocket (Fette and Melnikov, 2011) requests are received from the clients. The Flask framework (Ronacher, 2018) is used to generate and send HTML (HyperText Markup Language) pages to the client from HTTP requests. Flask-SockeIO (Grinberg, 2018) is responsible for receiving and responding to WebSocket requests.
- *Redis Server:* Redis (Carlson, 2013, RedisLab, 2018) is an in-memory database that can be used as broker since it implements the PubSub model. Redis allows the broker to be distributed across multiple nodes, that is, more than one Redis server can be used.
- *Processing Server:* one or more processing nodes. It was implemented in Python programming language.

All these modules may reside either on the same machine or on different machines interconnected by a data network. Redis performs load balancing to avoid processing overhead on only one of the processing servers. The client is a Web browser implemented in HTML and Javascript languages.

In this architecture, the processing servers subscribe to the broker (Redis server) to receive events.

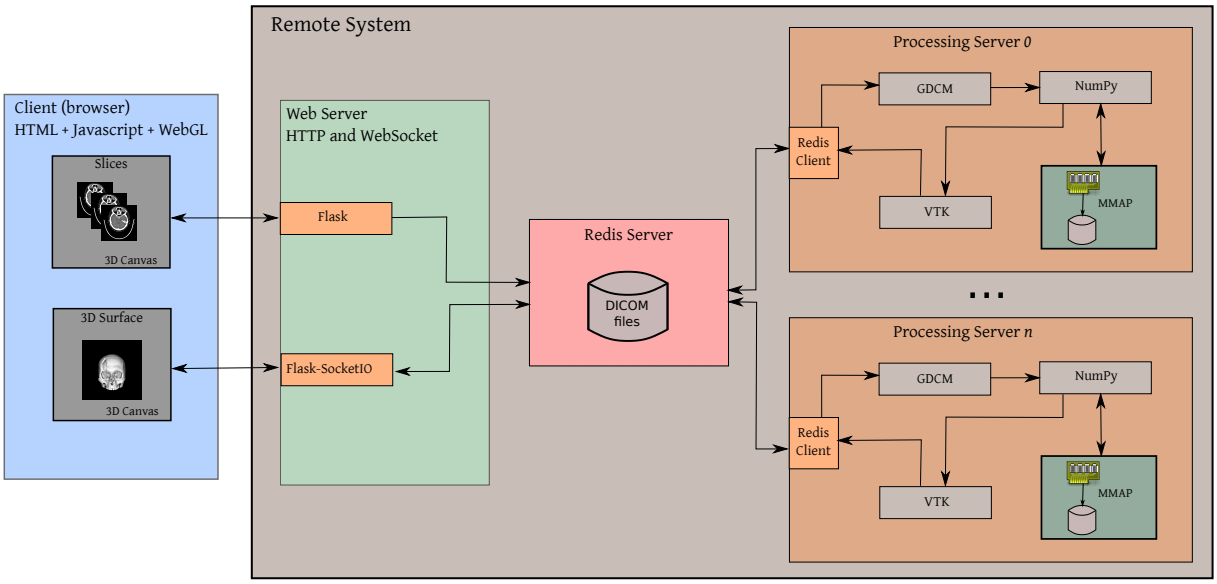


Figure 1: Diagram that illustrates the main stages of the proposed remote system for medical data visualization.

Examples of events include: 3D reconstruction, segmentation, mesh generation, and mesh rendering. The Web server receives client requests (via HTTP or WebSocket) and then sends an event to Redis with the data received from the client.

Redis stores the data in memory (or disk, if the data is too large) and contacts one of the processing servers registered in that event. The processing server accesses event data and performs processing. After performing the processing, the processing server sends a Redis event with the resulting data. The Web server subscribes to an event to receive these results. After receiving the results of the processing, the Web server sends them to the client.

Events in Redis are identified by a name (string). In order for the processing server to receive events related to the images in its possession, it subscribes to dynamically generated events. The same occurs with the Web server. This is necessary to not occur from the Web server sending the result to other client than the one that requested the result. This event name is generated by concatenating the operation to be performed with the image identifier. For instance, the segmentation operation for image `42` may have the event name `segment_image_00042`, whereas the Web server expects the result with the event `result_segmentation_image_00042`.

The workflow of the methodology starts when the client sends medical images (for instance, Computed Tomography, Magnetic Resonance Imaging, Microtomography) in the format DICOM (ACR/NEMA, 2018) to the distributed system via HTTP.

In the distributed system, the images are received by the Web server, which sends these images to one of the processing servers through a Redis event. When the event arrives at the processing server, it retrieves the images from the Redis server and removes those Redis images. From then on, all processing in these images is performed on that same processing server. This is done to avoid leaving the images stored on the Redis server.

On the processing server, the GDCM library (GDCM, 2018) is used to rebuild the images on a volume. The resulting volume is converted to a volumetric array using the numeric library Numpy (Oliphant, 2007) in conjunction with the VTK (Visualization Toolkit) library (Schroeder et al., 2004, VTK, 2018). The volumetric array is then written to a disk file. The file is mapped to memory via MMAP (Memory Map) (MMAP, 2018) using Numpy. Thus, only the portions of the data required for processing are kept in main memory and not the entire volume, which reduces the amount of memory required in the processing server.

After the data preparation (both two-dimensional and three-dimensional data) for visualization purpose, all the processing of subsequent steps is performed in the distributed system, where the client needs only to request data from the system and interpret them. All the available steps are listed as follows:

1. *3D Image Slice Visualization Tool:* this stage aims to allow the visualization of the slices in the axial, sagittal and coronal orientations. It starts with the request, by the client, using the HTTP protocol, of a given slice and orientation of interest. The Web server receives the request and sends an

event to Redis. The processing server with the corresponding image receives the event with the required data. The processing server retrieves the slice of interest in the file containing the volumetric array. Slice retrieval is done through file access with Numpy and MMAP. The processing server sends an event to Redis with the desired slice. The Web server subscribes to the corresponding event to receive the image. After receiving the image, it sends the image to the client. In possession of the image, the client renders it on the browser screen. Rendering is done by mapping the image in a plane as a texture. WebGL (WebGL, 2017) is used for rendering through JavaScript three.js (Cabello, 2018) library.

2. *Segmentation Tool:* segmentation is done through the double thresholding technique. In this approach, voxels are selected with gray levels between $T_{\min}$ and $T_{\max}$. The values of $T_{\min}$ and $T_{\max}$ are parameters controlled by the user through a graphical interface on the client. $T_{\min}$ and $T_{\max}$ are sent to the distributed system via HTTP. The Web server receives the request with the segmentation data and sends an event. This event is received by the processing server with the corresponding image to be segmented. It segments the images and sends the response through an event to the Web server. It sends a representation of this segmentation to the client via HTTP, which is a mask (in green color) superimposed on the voxels of the slice that are within the range of the threshold.
3. *Mesh Generation Tool:* after segmentation, the user can generate the three-dimensional surface, which is produced by the processing server using the marching cubes algorithm (Lorensen and Cline, 1987), implemented in the VTK library. A simplified version, containing fewer polygons of the three-dimensional surface, is also generated. The simplified surface is created using the decimation algorithm (Garland and Heckbert, 1997), implemented in the VTK library. The processing server sends the simplified surface to the Web server, which sends it to the client using the WebSocket protocol.
4. *3D Triangle Meshes Visualization Tool:* with the simplified surface, the client renders it using WebGL. Rendering of the simplified version occurs during user interaction with the visualization. After the interaction, the client sends a message requesting the rendering of the entire three-dimensional surface. This request is made using WebSocket and contains camera information (position, focus, and vector *up* that indicates the top side of the camera). This request arrives at the Web server, which sends the camera data to the processing server, via an event. The processing server renders the entire surface offscreen (Paul, 1997), according to the information sent by the client. The result is an image, which is sent to the Web server via an event. The Web server sends the client via WebSocket. The client then renders this image as plane texture with same dimensions as the renderer.

4 RESULTS

This section presents the results obtained with the implementation of the proposed methodology. Three server-side machines were used: (i) 1 server with Redis, (ii) 1 Web server with the proposed system and one of the processing nodes, (iii) 1 processing node.

On the client side, browsers were Mozilla Firefox (Desktop), Chrome (Android, Mobile) and Safari (iOS, Mobile). The only requirements on the client side are the availability of WebGL, WebSocket and Javascript.

Figure 2 illustrates the view of slices in the axial, coronal and sagittal orientations. Below each slice, there are sliders to change the slice to be displayed. In the lower right corner, it is possible to observe the segmentation tool based on thresholding. The threshold values are changed by dragging the sliders or typing the values directly. In the slices, it is possible to notice the mask (in green) superimposed on the slice indicating the segmentation.

Figure 3 shows the visualization of a three-dimensional surface. The visualization is done in two parts: the rendering of the simplified mesh, which is performed on the client, and the complete rendering, which is performed by the server. Simplified rendering is performed while the user interacts with the mesh. Figure 3a illustrates this rendering. Figure 3b shows the result of rendering the complete surface, which is performed after the user interaction.

The proposed architecture proved to be very flexible by allowing the tool to be used on different mobile systems, such as Android and iOS. This makes it possible to use the system in non-desktop environments, which could occur during a doctor's visit to a patient's bed. Figure 4 illustrates the surface rendering interface on Android 6.0 and iOS 10.3 systems.

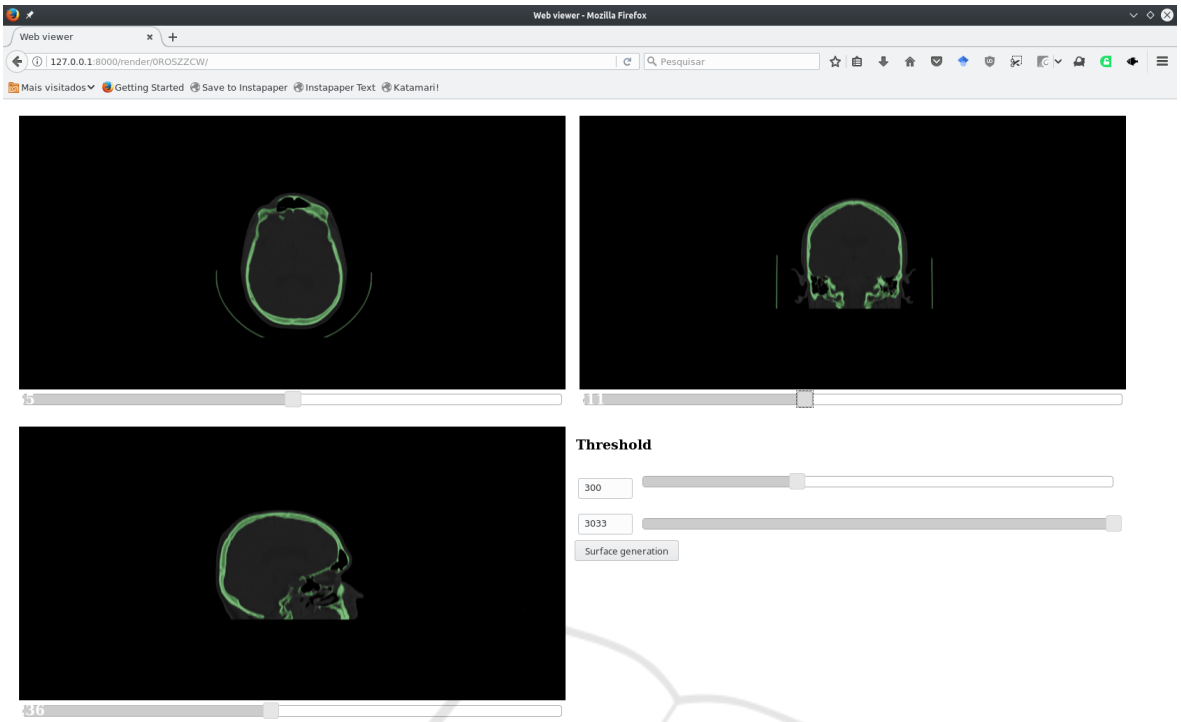
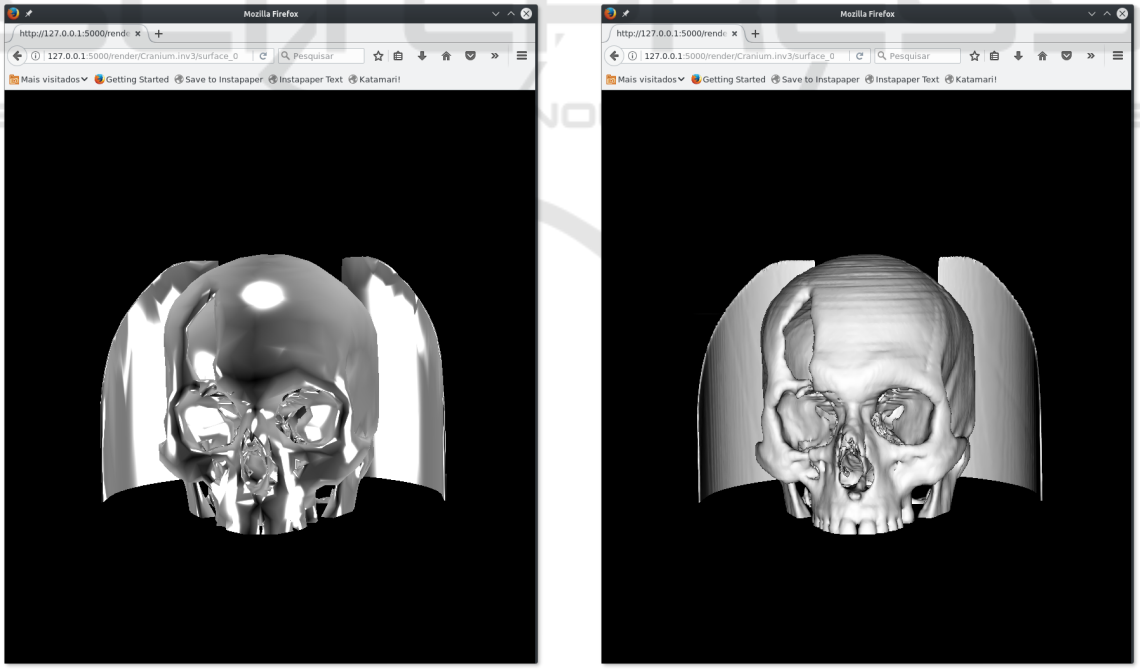
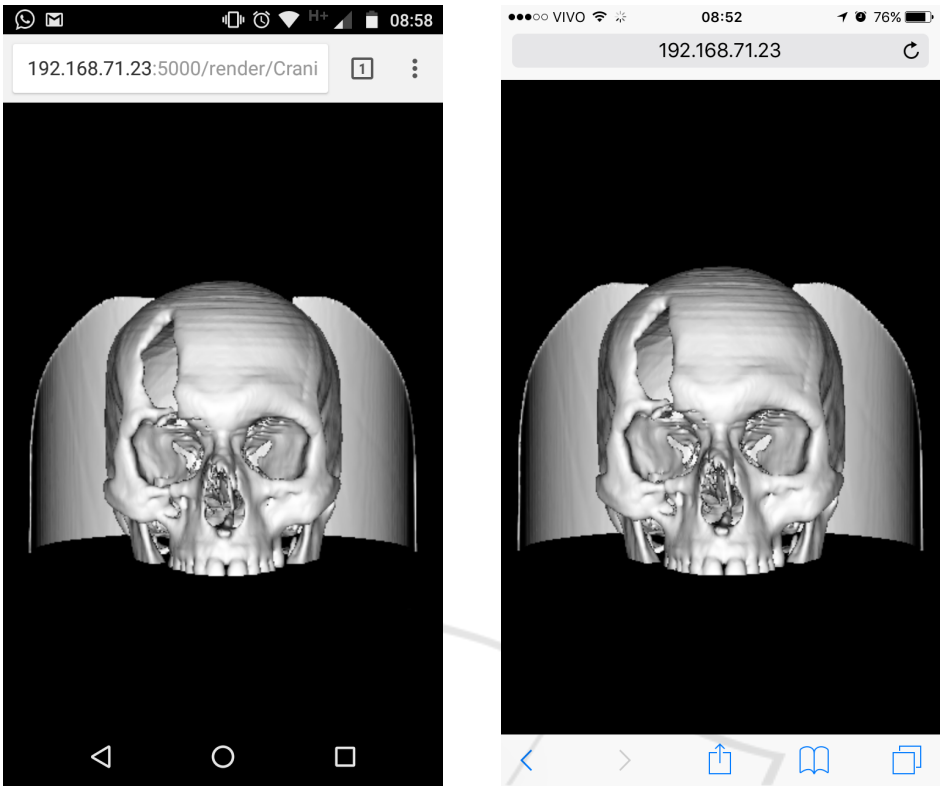


Figure 2: System interface used to visualize the slices in the axial, coronal and sagittal orientations.



(a) simplified surface (b) complete surface

Figure 3: Surface rendering on a Web browser.



(a) Android (b) iOS

Figure 4: Result of surface rendering on a smartphone Android version 6.0 and iOS 10.3.

5 CONCLUSIONS AND FUTURE WORK

The distributed system for medical image visualization via Web was implemented and proved to be very useful. This makes it possible to centralize the processing and offer such computing resources to hospitals and clinics that do not have much computational power.

The possibility of accessing the system via mobile browser will allow access to the rendering system on smartphones, which may be useful for physicians and dentists when a desktop computer is not available.

Directions for future work include improvements in triangle mesh generation, automated tools for correcting mesh problems (such as holes and face normal reversals), and other segmentation tools, for instance, watershed and region growing. We also intend to incorporate the developed system into the open-source InVesalius (InVesalius, 2018, Amorim et al., 2015).

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