CHAPTER 9

MEDX3DOM: MEDX3D for X3DOM

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Context

The Web3D consortium develops standard for the visualization of medical images and a great collaboration between the consortium and the research group for volume visualization integrated by Vicomtech and CAD/CAM/CAE Laboratory was stablish. This work present an integration of the methodologies developed for volume visualization in the standard of MEDX3D of the Web3D.

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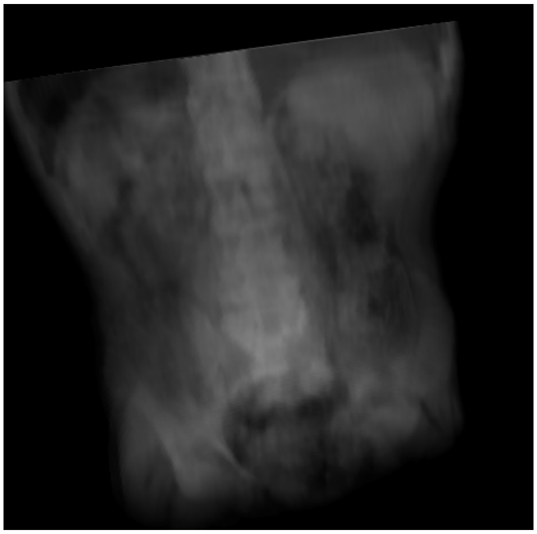

FIGURE 9.1. X-ray style volume rendering with *MEDX3DOM*

Abstract

We present an implementation of *MEDX3DOM* a *MEDX3D* standard implemented into the *X3DOM* framework. The article present the report of a work in progress of the implementation identifying the critical sections to be migrated into the new architecture, and possible extensions of the standard on the Web environment. Results for the early implementation are shown, where the visualization of medical datasets with advance direct volume rendering algorithms is obtain under the X3DOM architecture with interactive framerates and good image quality. An example of the HTML5/X3DOM document is presented and its result is shown. Preliminary results are discussed and future work is presented.

1. Introduction

MEDX3DOM is a work in progress implementation to support advanced medical visualization functionality on the Web without plugins. It is based on the ISO standard *MEDX3D* (Ref. [**116, 117**]) and implemented into *X3DOM* (Refs. [**99, 118, 119**]). *MEDX3DOM* is based on the previous work for volume visualization in WebGL (Refs. [**115, 120**]). *MEDX3DOM* reads medical data in diverse formats such as *DICOM*, *NRRD* and Raw formats. The output is defined by a collection of volume visualization styles for Direct Volume Rendering (*DVR*) algorithms.

DVR algorithms were initially presented by Blinn and Kajiya (Ref. [**121, 122**]) allowing the visualization of all inner characteristics of volumes at once. A comparison between different *DVR* algorithms, such as Texture Mapping, Raycasting, Splatting or Shear Warp, was presented [**123**]. Raycasting is one of the best algorithms for *DVR* which was proposed by Levoy (Ref. [**85**]). Its main idea is to calculate the volume rendering integral along rays launched from the view window into the volume. Thus, in this method, the color and opacity of each pixel in the final image are evaluated by accumulating the contribution of discrete samples of the ray that intersects the volume. Futher developments in raycasting for accelerated hardware using *OpenGL* were collected by Hadwiger (Ref. [**86**]).

The Khronos Group released the *WebGL 1.0* Specification in March 2011. It is a JavaScript binding of *OpenGLES 2.0 API* and allows a direct access *GPU* graphical parallel computation from a web-page. Calls to the *API* are relatively simple and its implementation does not require the installation of external plug-ins, allowing an easy deployment of multi-platform and multi-device applications. Browser based

3D middleware frameworks have been presented using *WebGL* as a rendering backend such as GLGE[1], SpiderGL (Ref. [**124, 125**]), SceneJS[2], WebView3D[3], XTK[4]. *XML3D* (Ref. [**126**]) and *X3DOM* (Ref. [**99**]) present a declarative model for 3D visualization on Web using *WebGL* as one of the backends.

Declarative programming is a model of data and logic representation focused on the description of the model more than the control flow. Markup languages are one of the declarative models which are extensively used in the web, e.g. *HTML*, *XML*, *SVG*, *MATHML*, etc. *X3D*[5] is a declarative *XML*-based markup lenguage for the representation of 3D data. *MEDX3D* is an extension of *X3D* supporting the advanced medical visualization functionality.

Medical visualization is a challenging scientific field since the interpretation of images leads to clinical intervention. Therefore, quality and fast interactive response are important features in this domain. Remarkable advances have occurred in medical imaging technology and recent applications supports the possibility of sharing imaging data online across clinical and research centers and among clinicians and patients. Image formats such as *DICOM* or *NRRD* allow to store medical volume data acquired by diverse techniques such as computer tomography (*CT*), magnetic resonance imaging (*MRI*), diffusion magnetic resonance imaging (*dMRI*), positron emission tomography (*PET*), ultrasound and others. A formalized and standardized model of visualization for medical imaging allows a correct interpretation of the images in heterogeneous architectures like Internet.

The contribution of this article is the implementation of the *MEDX3D* standard using the *X3DOM* architecture, allowing the advanced medical visualization functions to be used in heterogeneous architectures. Also the generation a common framework for medical visualization which can be used, formalized, extended and tested in several devices and platforms.

The article is organized as follows. Section 2 presents the work related to this article, including a description of volume rendering techniques, visualization of medical images. The methodology of the developed work is explained in Section 3. Then, the results accomplished are presented in Section 4, and finally, Section 5 states future developments.

2. Related Work

2.1. Visualization of Medical Images. Advanced visualization of medical images require the use of algorithms with high computer processing demand. Client/Server architectures allow the distribution of computer processing in several models. They can be classified as Fat Client, Thin Client and Hybrid. Each one of them has specific characteristics.

2.1.1. *Fat Client.* In the Fat Client model, all the processes are made in the client, freeing the server for data storage and communication only. This approximation depends heavily of the processing power of the client and the visualization quality or interactivity of the application is not guaranteed. Masseroli (Ref. [**127**]) presents an architecture based on Java Applets in which the server is used for storage and communication only, the visualization of medical images is based on 2D slices of the datasets and basic tools for editing are implemented. Hamza (Ref. [**128**]) presents an architecture for the visualization of medical images in 3D as a set of surfaces with transparency using X3D. Cantor Rivera (Ref. [**129**]) presents a visualization framework based on the libraries of *VTK*[6] for reading images and extracting the geometry, and uses WebGL for the client rendering.

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[1] www.glge.org

[2] www.scenejs.org

[3] www.arivis.com/en/arivis-WebView/arivis-WebView-3D

[4] www.github.com/xtk/X/wiki

[5] www.web3d.org/x3d/

[6] www.vtk.org

2.1.2. *Thin Client.* Thin client allows the use of lightweight clients for visualization, but all the computational process is performed in the server. Scalability of the system is very difficult to achieve because for each new client using the service the server load increase. Nevertheless, the use of this model allows the use of low power devices and the visualization is the same for all the clients. Poliakov (Refs.[**130, 131**]) presents a model of Web Service visualization for medical imaging where the render is made on the server and send to a *JAVA* client application through the network. Blazona (Refs. [**132, 133**]) presents an architecture where the client uses *X3D* web plugins for the final visualization but the server side is responsible to generate the models that will be visualized. Smelyanskiy (Ref. [**134**]) presents a set of medical visualization algorithms optimized for parallel architectures and distributed computing.

2.1.3. *Hybrid.* Hybrid methods share the processing capabilities of the server and the client, but, since communication is required, network latency can generate several problems for the generation of the integrated images. Yoo (Ref. [**135**]) presents a hybrid method which uses video streaming for the visualization of volume models integrated with geometry data in the client. Seamless visualization of volume data and geometry can be found in the work of Mahmoudi and Settapat (Refs. [**136, 137, 138**]), these works uses the client's 3D capabilities but uses server processing for the heavy computational process and the extraction of specific visualizations. These models also allow the implementation of advanced tools of image processing and collaborative visualization. A very interesting approximation for hybrid models was presented by Jomier (Ref. [**139**]), in which the visualization of large datasets can be performed and different backends for rendering, depending on the client capabilities, are used.

2.2. MEDX3D. *MEDX3D* (Ref. [**116**]) is an extension of the *X3D* ISO standard to support advanced medical visualization functionality. The standard presents a set of tags which allow to read different volume formats such as *DICOM*, *NRRD* or Raw data. Also, the standard defines volume styles visualizations which allow to render with different non-photorealistic models, enhancing specific regions of the volume which normally represent interesting regions to be visualized, such as edges, blobs and occlusions. Several applications on Web are used in medical fields (Ref. [**103**]). One of the applications is medical training simulations (Ref. [**140**]). In this work a simultaneous visualization and haptic interaction was presented. Extensions for the *MEDX3D* standard are proposed by Fried and Ullrich (Refs. [**141, 142**]).

3. Methodology

MEDX3DOM implements the standard *MEDX3D* in *X3DOM*. The implementation is based on the generation of the nodes for two components: Texturing3D and VolumeRendering. The actual status of the implementation declares all nodes for *X3DOM* architecture but only the some basic functionality are implemented.

Texturing3D nodeset define the tags to work with the information of 3D data, specific readers for file formats such as *DICOM*, *NRRD* and raw data are part of the standard. Other kind of data sources could be implemented like *WADO*, which is an specification for a WebService to obtain *DICOM* data. 3D texture data is normally stored in a **Texture3D** structured which is part of common 3D APIs like *OpenGL*. This structure is not available in WebGL and a mapping between a Texture3D and a Texture2D was define in order to overcome this limitation. This mapping is defined as a shader function (Fig. 9.2).

Volume data is storage in atlas format. An example of medical volume dataset represented in this format is shown in figure 9.3. This model of representation also allows the storage of preprocessed data such as image gradients shown in figure 9.4, where each color magnitude represent the direction of the gradient vector for each axis.

Given the flexibility of the *X3DOM* architecture the transfer functions can be store as images, an example of a two dimensional transfer function is presented in figure 9.5. Its also possible to use a video

```
vec4 cTexture3D(sampler2D uData,vec3 volpos)
{
  float s1,s2;
  float dx1,dy1;
  float dx2,dy2;

  vec2 texpos1,texpos2;

  s1 = floor(volpos.z*numberOfSlices);
  s2 = s1+1.0;

  dx1 = fract(s1/slicesOverX);
  dy1 = floor(s1/slicesOverY)/slicesOverY;

  dx2 = fract(s2/slicesOverX);
  dy2 = floor(s2/slicesOverY)/slicesOverY;

  texpos1.x = dx1+(volpos.x/slicesOverX);
  texpos1.y = dy1+(volpos.y/slicesOverY);

  texpos2.x = dx2+(volpos.x/slicesOverX);
  texpos2.y = dy2+(volpos.y/slicesOverY);

  return mix( texture2D(uData,texpos1),
    texture2D(uData,texpos2),
    (volpos.z*numberOfSlices)-s1);
}
```

FIGURE 9.2. GLSL Fragment shader function to map a volume coordinate to a texture 2D atlas, the variables $numberOfSlices$, $slicesOverX$, $slicesOverY$ are uniforms and represent the number of slices of the volume, the rows and columns.

texture for transfer functions or volume data, allowing the animation of the models without a maintaining the interactivity of the visualization and showing the image in a dynamic way (Fig. 9.6).

The implementation of the MEDX3D standard into X3DOM allows the declaration of volume visualization in X3D and visualized the render in browser without the use of plugins. The files follow the standard MEDX3D but the image texture is defined as a **Texture2D** structure. The file format is presented in the figure 9.7, were an extraction of and HTML5 file is presented were a volume is rendered in a webpage.

4. Results

We present an early implementation of the *MEDX3DOM* proposal, which allows visualization of medical volume datasets following the guidelines of the *MEDX3D* standard. The implementation is partially integrated with *X3DOM* using the *WebGL* backend and showing some basic styles of volume rendering.

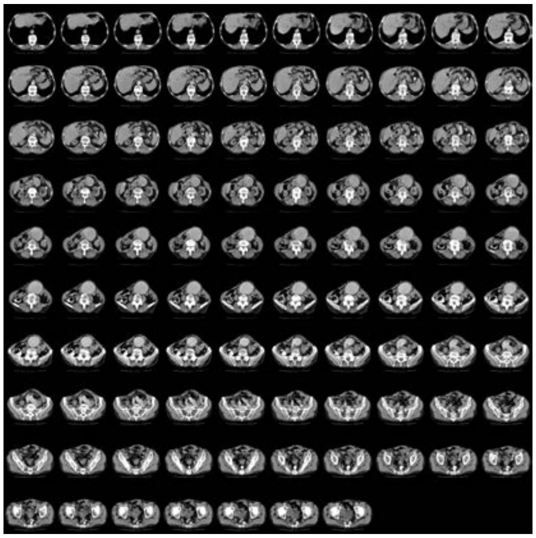

FIGURE 9.3. Texture atlas with the volume data for the aorta dataset

FIGURE 9.4. Texture atlas with the volume gradient data for the aorta dataset, enhanced color for better visualization.

Data reading is implemented using the previous model of image atlas, but different test show the easy integration of *NRRD* and raw data readers into Javascript and *X3DOM*. *DICOM* is a very extensive and complicated file format and the implementation of a reader in Javascript its not recommended. But compiler translation technologies like *emscripten*[7] allows the generation of Javascript code from C or C++ languages, some test show the correct implementation for image formats as *TGA* or *JPEG2000*, the translation of *DICOM* format could be possible and some libraries had been initially tested such as *DCMTK*.

Volume storage in the client is made with a **Texture2D** structure, the limit of the structure in the *WebGL* implementations restricts the size of the volume to be rendered. Some alternatives can be implemented such

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[7] www.github.com/kripken/emscripten

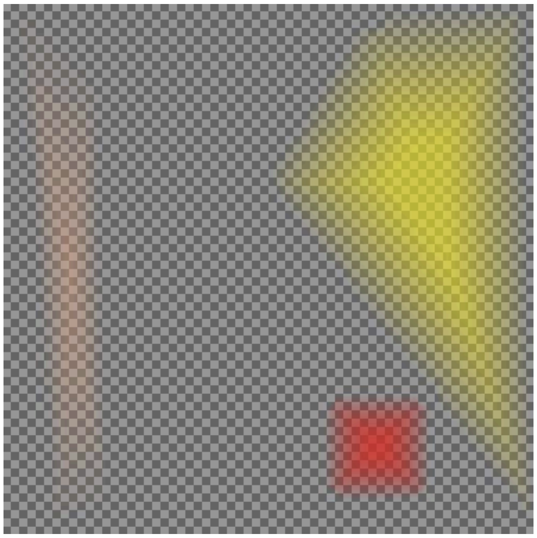

FIGURE 9.5. 2D transfer function image, background squares represent are presented to visualize the transparency value.

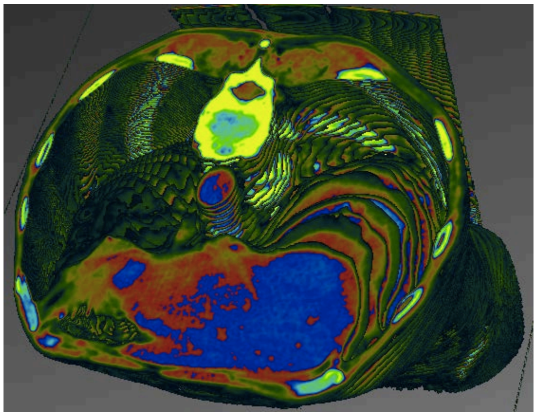

FIGURE 9.6. Volume rendering with a color-full transfer function.

as Level of Detail for volumes or Compressed Textures. Nevertheless this restriction is hard to solve and the impact in the visualization is critical in low graphics memory devices.

Volume Styles are not fully implemented, and only some simple styles are presented. The render pipeline of the Styles follow the implementation of *H3D*. It's expected that the other styles could be easily integrated into the architecture.

5. Future Work

Optimization models for the raycasting algorithm such as empty space skipping, pre-multiplied transfer functions, ray jitter can be integrated into the rendering pipeline to enhance the quality of the render. Other visualization models such as Multi-Planar Reconstruction (*MPR*) are going to be integrated in *MEDX3DOM*.

Vector fields are another representation for medical visualization used specially for *dMRI* datasets. This representation need preprocessing models to be visualized know as Flow Visualization (Ref. [**143**]). Linear Integral Convolution (*LIC*) is a methodology to visualize this kind of data and will be integrated in the implementation.

```
<html>
<head> ... </head>
<body>
<h1>Volume Rendering</h1>
<X3D xmlns=’http://www.web3d.org/specifications/x3d-namespace’
 showStat=’true’ showLog=’true’ width=’500px’ height=’500px’>
  <Scene>
    <Background skyColor=’0 0 0’/>
    <Viewpoint description=’Default’ zNear=’0.0001’ zFar=’100’/>
    <Transform>
      <VolumeData id=’volume’ dimensions=’4.0 4.0 4.0’>
        <ImageTexture containerField=’voxels’
         url=’aorta4096.png’/>
        <OpacityMapVolumeStyle> </OpacityMapVolumeStyle>
      </VolumeData>
    </Transform>
  </Scene>
</X3D>
</body>
</html>
```

FIGURE 9.7. HTML/X3DOM file fragment to visualize a volume using *MEDX3DOM*, Texture image defined in atlas format

Hybrid visualization of volumes and geometry is important for the visualization of medical dataset where the volume is registered with other geometry, e.g. Brain Volumes and Tractography (Ref. [**144**]), Head Volumes and Dental Surfaces, etc. This hybrid visualization is going to be integrated in *MEDX3DOM*.

Transfer functions are a fundamental tool for the correct visualization of volumes. Prototypes of automatic generation of transfer functions by visual clues, know as Visual Volume Attention Maps (*VVAM*) (Ref. [**145**]), has been developed and the methodologies are going to be tested in *MEDX3DOM*.

Use of the volume rendering technology can be used for other datasets besides medical images, such as geovisualization of weather data (Ref. [**146**]), ocean data, underground structures or mechanical components. Some of this datasets are going to tested in the implementation.

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