Interactive visualization of volumetric data with WebGL in real-time

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Problem

Rendering of volumetric data with the following …

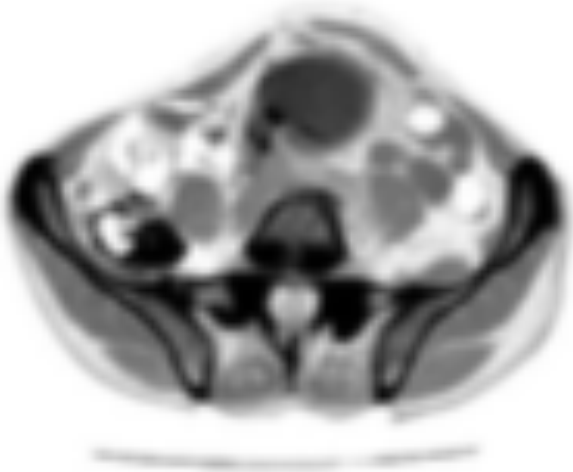
- Real-time
- Realistic
- Interactive

…supported through a web-browser

Problem Domain Background

Medical

Medical imaging techniques such as CT scan, MRI, and PET produce sets of parallel slices that form volumetric dataset.



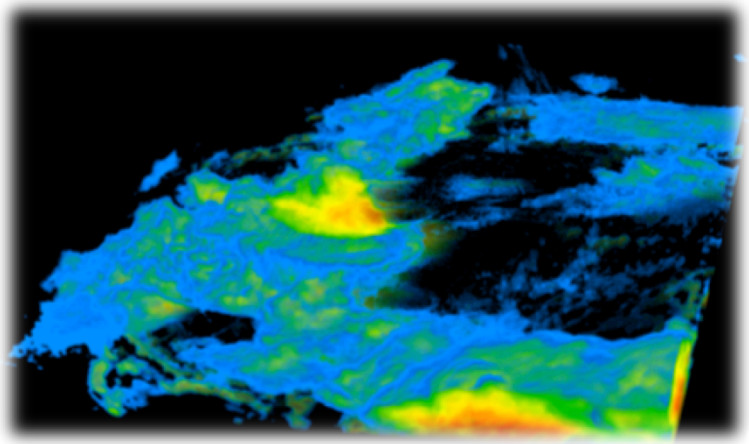
Storage and Distribution of medical images are managed by a Picture Archiving and Communication Systems (PACS)

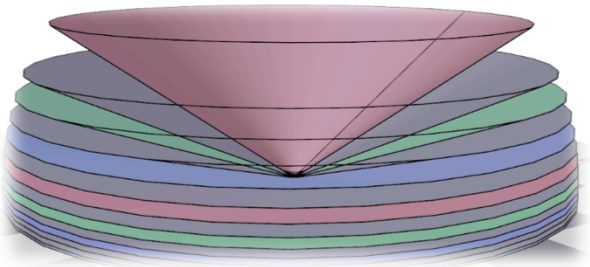
- Client −to- Server architecture
- Requires specialized software

Weather

Weather data is also volumetric

- Collected by using radar that scans a volume surrounding it
- Collects values in a circular or conical scan surface
- Doppler radar also samples physical variables (reflectivity, radial velocity etc)





Congote et al, 2011

Problem Domain Motivation

- Scientific fields such as Medical Imaging and Meteorology have been pioneers in 3D visualization
- Visualization is the primary target of analysis by Radiologist and Meteorologist
  - The advent of CT and MRI scans provides slices of images that can be used to render 3D volumes
  - 3D volume rendering as a basis for visual assessment by radiologist is still new and not widely used.
  - May require re-training for how radiologists diagnose
- Improving fidelity and dimensionality of the visualization can directly improve the overall accuracy of the decision making.

Background and Prior Research

- Volume Rendering seeks to project a 3D model into 2D image
  - The ability to interact in real-time gives the illusion of a 3D image

- Prior to WebGL, 3D visualization was performed through native applications or non-standard plug-ins installed in the web browser
  - Requires access to local hardware (i..e GPU)

- Mostly rendering polygon meshes
  - Straightforward and supported by GPU raster rendering

Background: Volume Rending

Marc Levoy - considered a pioneer in volume rendering; worked on visualizing CT imaging

LEVOY, M. 1988. Display of surfaces from volume data. *IEEE Comput. Graph. Appl. 8*, 3, 29–37.

Demonstrated that volume-rendering techniques produced better images from volumetric data than using conventional geometric primitives.

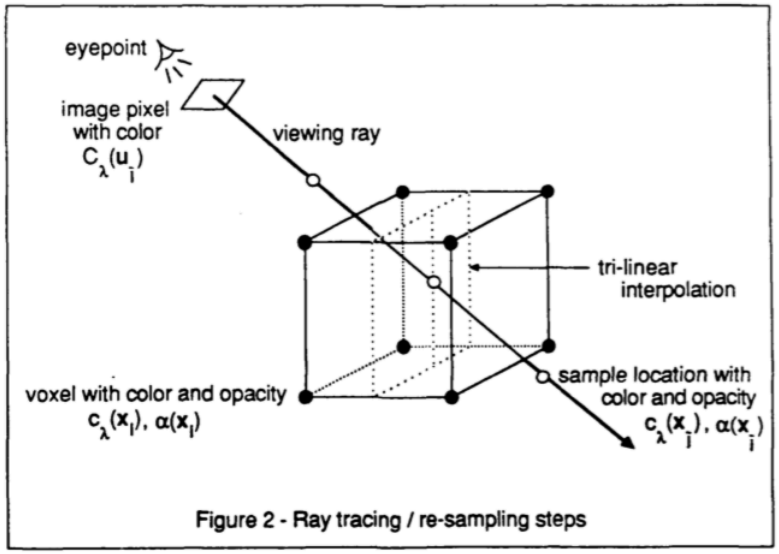
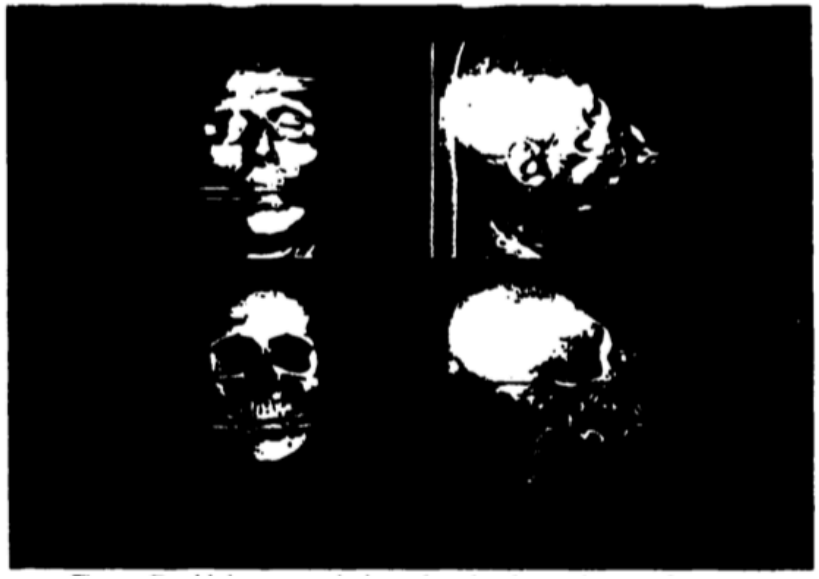


Figure 2 - Ray tracing / re-sampling steps

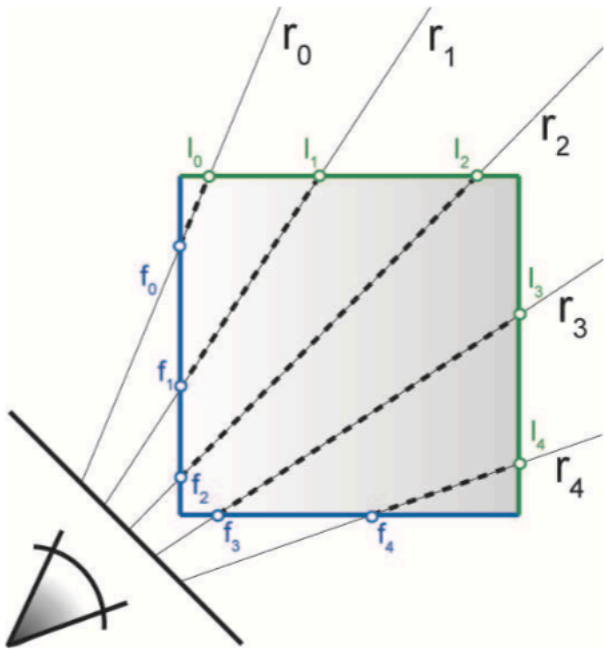


Levoy, 1988

Hadwiger et al - Volume Ray casting

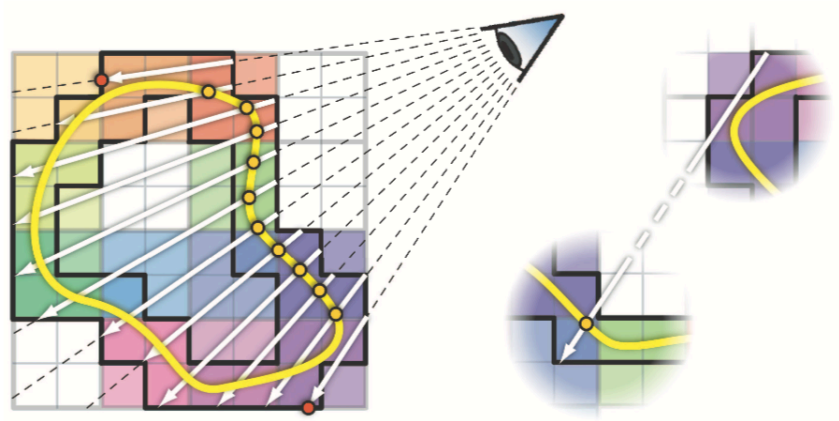
HADWIGER, M., LJUNG, P., SALAMA, C. R., AND ROPINSKI, T. 2009. Advanced illumination techniques for gpu-based volume raycasting. In *ACM SIGGRAPH 2009 Courses*, ACM, 1–166.

- Describes Volume ray-casting is most basic, but most flexible volume rendering algorithm
- Ray-casting as a numerical method for evaluating volume rendering integral
  - Integral is based on integrating light interaction effects along a viewing ray on the optical model
  - Absorption – radiant energy absorbed over distance
  - Alpha Blending – combining translucent foreground color with background color



Volume is sampled at regular intervals between starting and ending positions

Empty skipping and establishing bounding geometry



Hadwiger et al, 2009

Proposed Method

Congote, J., Segura, A., Kabongo, L., Moreno, A., Posada, J., & Ruiz, O. (2011, June). Interactive visualization of volumetric data with webgl in real-time. In Proceedings of the 16th International Conference on 3D Web Technology (pp. 137-146). ACM.

- Approach relies on Levoy and Hadwiger et al work on volume rendering algorithms
- Adapted Volume Ray-casting algorithms for WebGL
- Volume interpolation from 2D image slices
- Avoids use of server-side for remote rendering, enabling better scalability for large-user environments (such as in medical imaging)
  - Does not require preprocessing
- Realism is accomplished through the use of blending functions, transfer functions, and Phong illumination

Method Details

Composing Texture from Image slices

- Construct a "texture" by transforming individual image slices into mosiac (matrix) of images
- Uses interpolation to fill in the gaps in between the slices

Identification of Ray coordinates

- Uses a cube as the bounding geometry for the image being rendered
- Renders the cube into scene using view point
- First renders the color using depth function change
  - 1st pass presents closest region of the cube to the camera
  - 2nd pass presents far region

Ray generation

- Ray is calculated from front region to back region
  - Color interpolation is used
- Cartesian x,y,z coordinates defined where one dimension is an image slice selector and the other two is a coordinate within that image
- Ray is divided by S steps (number of samples)
  - Compute x,y,z for each sample in the volume
  - Value of position is interpolated from the texture

Transfer Function

- Use value of texture at (x,y,z) to identify color
- Use color in composition function
- Ray finishes when composition function reaches the end in the cube
- Assigns color value to each pixel along the ray

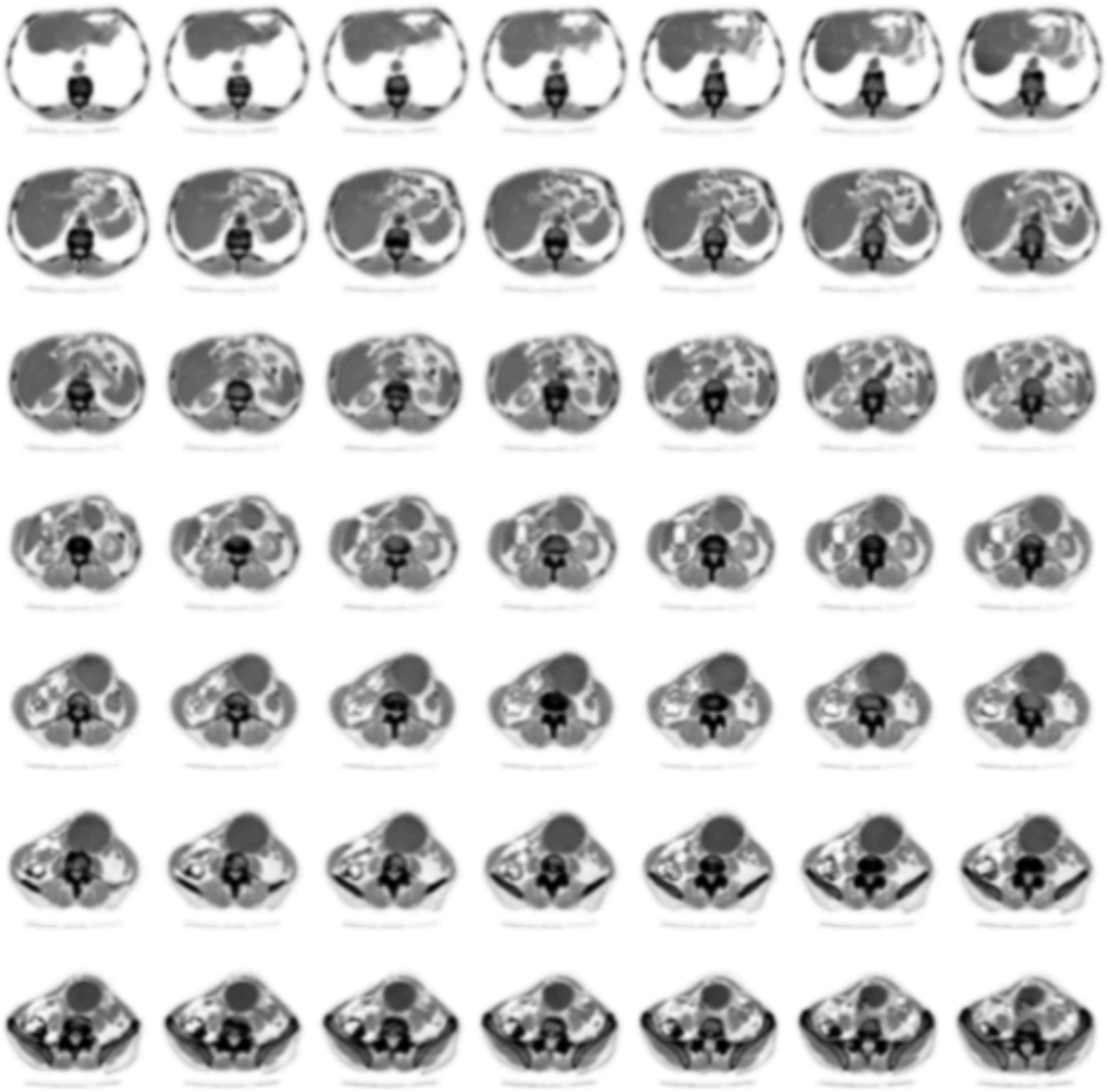
$$S_a = V_a * O_f * \left(\frac{1}{s}\right)$$

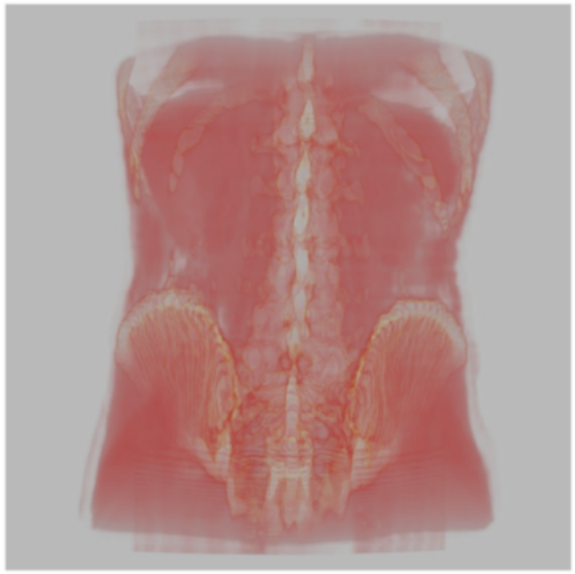
$$S_{rgb} = V_{rgb} * S_a * L_f$$

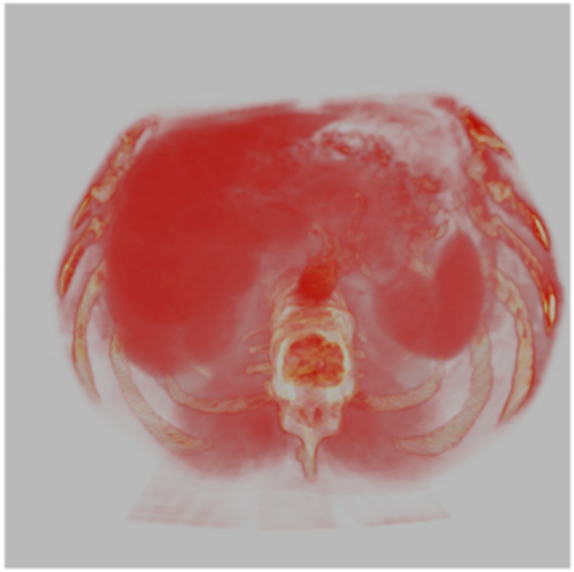
$$A_{rgb}^k = A_{rgb}^{k-1} + \left(1 - A_a^{k-1}\right) * S_{rgb}$$

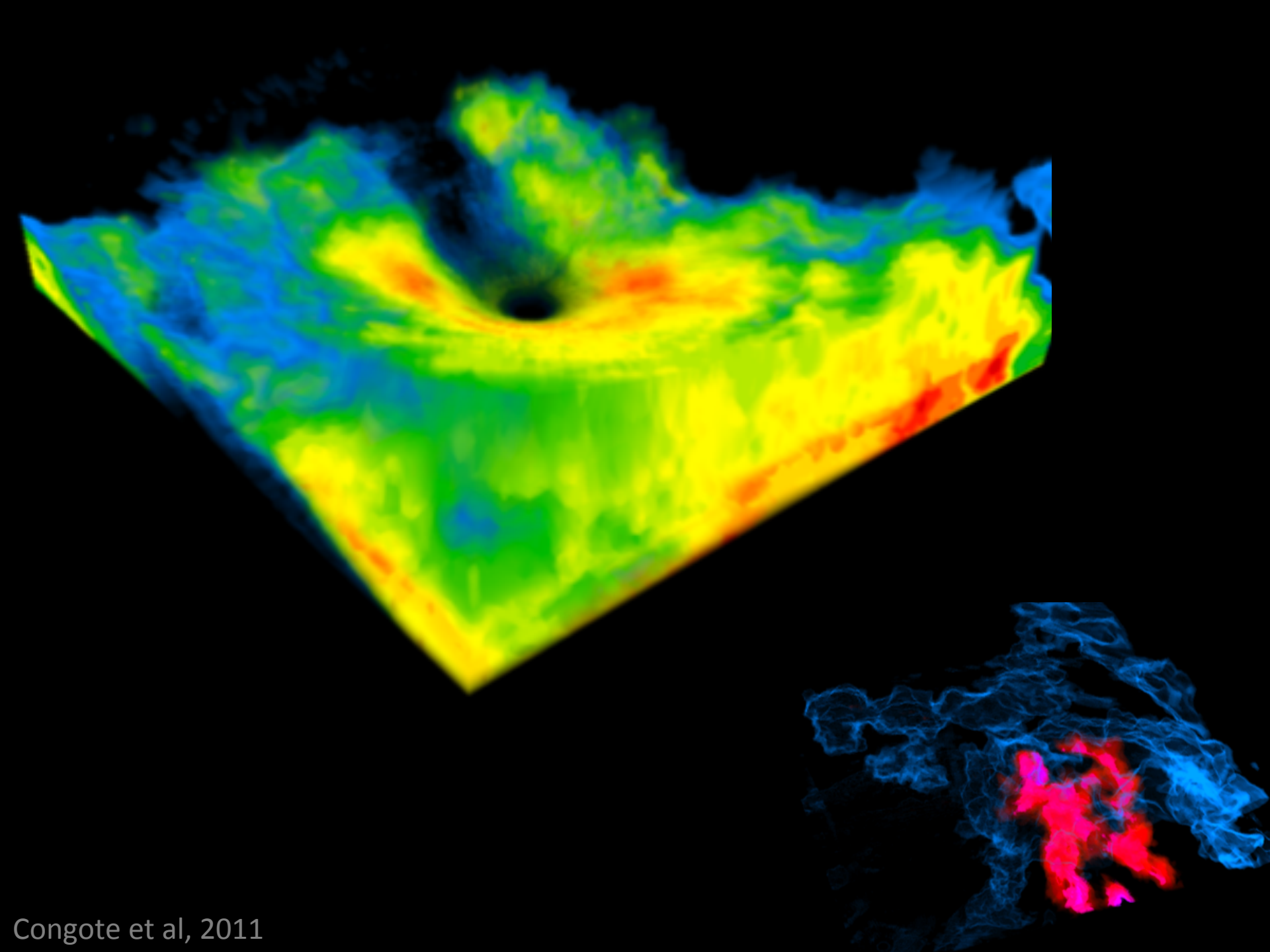
$$A_a^k = A_a^{k-1} + S_a$$

CT Image Slices used for Volume Rendering









Congote et al, 2011

Performance Results

Browser	N. Steps	Load Time (msec)	frame rate (frame/sec)	Memory (MB)
FirefoxDX	80	16677	69	204
FirefoxGL	80	308	94	102
Chrome	80	18062	77	153
Opera	80	82	108	74
FF-nA	140	302	60	95
Opera	140	118	66	73
FirefoxGL	170	281	51	95
Opera	170	102	54	77
FirefoxGL	200	312	44	96
Opera	200	111	48	81

Demo of CT Scan 3D Rendering

Congote, J., Segura, A., Kabongo, L., Moreno, A., Posada, J., & Ruiz, O. (2011, June). Interactive visualization of volumetric data with webgl in real-time. In Proceedings of the 16th International Conference on 3D Web Technology (pp. 137-146). ACM.

http://demos.vicomtech.org/volren/

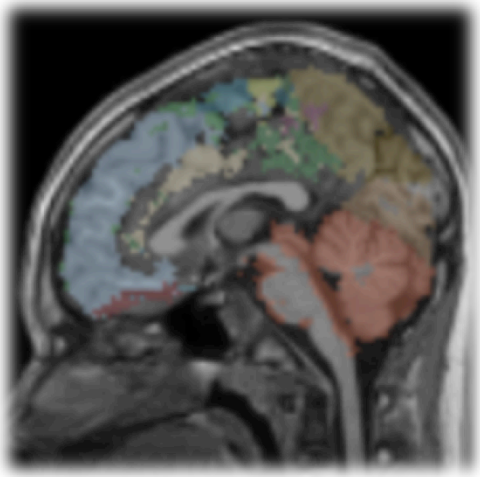
Related Work

Qiao, L., Chen, X., Zhang, Y., Zhang, J., Wu, Y., Li, Y., ... & Qiu, M. (2017). An HTML5-Based Pure Website Solution for Rapidly Viewing and Processing Large-Scale 3D Medical Volume Reconstruction on Mobile Internet. International journal of telemedicine and applications, 2017.

- Combine surface rendering combined with remote volume rendering
- WebGL based on client side and native process for volume rendering
- Solution for 3D medical volume reconstruction
- Claim it is "pure web environment", but relies on remote rendering called "master-slave"

Haehn, D., Rannou, N., Ahtam, B., Grant, E., & Pienaar, R. (2014). Neuroimaging in the browser using the X Toolkit. *Frontiers in Neuroinformatics*, *101*.

- XTK – "The X Toolkit"
- Claims to be first WebGL / JavaScript-based visualization for medical imaging
- http://socr.umich.edu/HTML5/BrainViewer/



Review

- A general concern on the effects of interpolation and other simulations that can distort or mislead an expert

- Latency for loading the original images (which can be very large in medical imaging)
  - Consider compression optimizations, video compression schemes may help eliminate temporal redundancy
- Surface rendering for textures can be very helpful to radiologists
- Explore use of ThreeJS framework to abstract from WebGL (such as XTK and ATM)
- Reduced Resolution
  - Medical Images use large sample bit depth (vs common 8bit)
- Issues with reliability and consistency of Javascript setTimeout() function having a 10ms overhead per call, causing performance issues
- Exposing additional controls for manipulating lighting, may be helpful

References

Reviewed Paper:
Congote, J., Segura, A., Kabongo, L., Moreno, A., Posada, J., & Ruiz, O. (2011, June). Interactive visualization of volumetric data with webgl in real-time. In Proceedings of the 16th International Conference on 3D Web Technology (pp. 137-146). ACM.

Congote, J., Segura, A., Kabongo, L., Moreno, A., Posada, J., & Ruiz, O. – Demo of Real-Time Interactive Visualization of Volumetric Data with WebGL. http://demos.vicomtech.org/volren/.

Additional papers
HADWIGER, M., LJUNG, P., SALAMA, C. R., AND ROPINSKI, T. 2009. Advanced illumination techniques for gpu-based volume raycasting. In *ACM SIGGRAPH 2009 Courses*, ACM, 1–166.

Haehn, D., Rannou, N., Ahtam, B., Grant, E., & Pienaar, R. (2014). Neuroimaging in the browser using the X Toolkit. *Frontiers in Neuroinformatics*, *101*.

LEVOY, M. 1988. Display of surfaces from volume data. *IEEE Comput. Graph. Appl. 8*, 3, 29–37.

Min, Q., Wang, Z., & Liu, N. (2018). An Evaluation of HTML5 and WebGL for Medical Imaging Applications. *Journal of healthcare engineering*, *2018*.