2014 OSEHRA Open Source Summit
Global Collaboration in Healthcare IT
OSEHRA September 3-5, 2014 - Bethesda North Marriott Hotel & Conference Center, MD

X3D Scene Graph Structures for Medical Image Metadata

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Reproducible Visualization

*… across applications, across the **WWW***

- Introduction:
  - Technology survey & status
- Requirements:
  - Clinical
  - Training & simulators
  - Web Publishing
  - 3D Printing
- **Solution:**
  - ***Metadata + Graphical objects in ISO X3D !***

Interoperable Digital Heath Records

- Informed consent
- Patient education (personalized)
- Simulation
  - Training
  - Planning
- Therapeutic adjunct
  - Surgery
  - Procedures
- Health Information Exchange
  - Image markup
  - Animation
    - Fly throughs
  - Standard rendering
- Visual analytics

Share information

Increase efficiency

Empower patients

Increase transparency

Leverage technology for new insights

Source: IHI Triple Aim

Health Information Exchange

DICOM

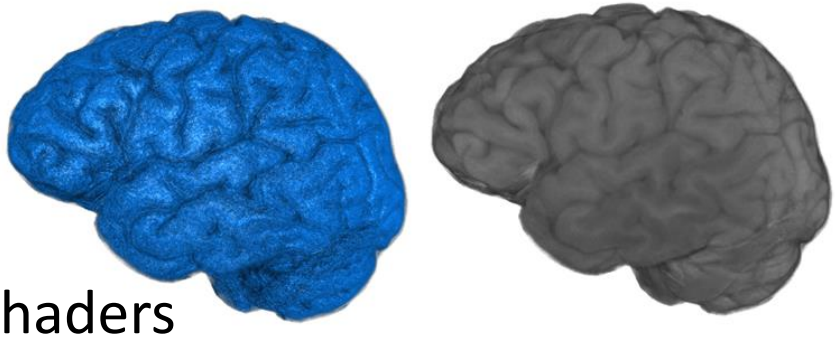
- Clinical standard format; large, sprawling spec includes:
  - Volume data encoding
  - Includes data structures for segmentation & surface data
- Does not hold 3D & 4D presentation state information:
  - Volume rendering algorithms
  - Surface Materials & composition
  - Lighting
  - Viewpioints, Camera animations

ISO X3D Volume Rendering & Metadata

- ISO standard for n-D Presentation
  - X3D Volume rendering
  - X3D Surface rendering
  - X3D 3D Printing

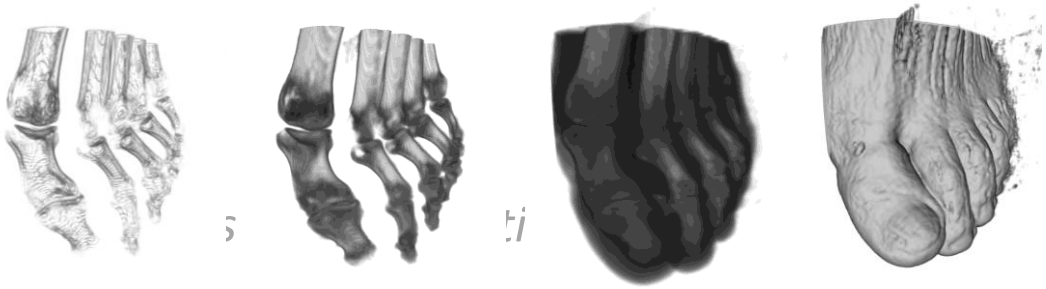
- Metadata practice:
  - Metadata and Metadata Sets can be children of any node in the scene graph
  - DEF, reference, name and value attributes can be used to integrate ***ontology terms and provenance***

Volume Presentation



Many techniques:

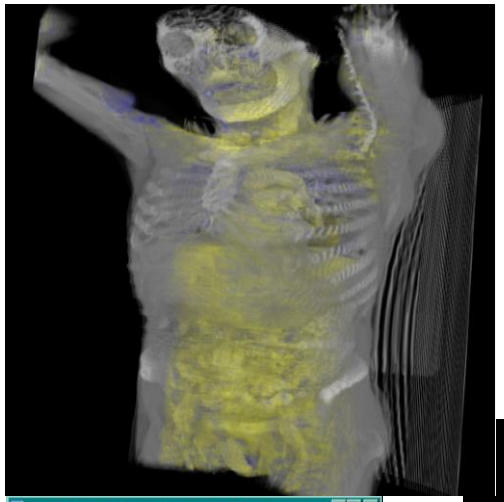
- Volume rendering
  - 3DSplatting, ray tracing, pixelshaders
  - Established CPU and GPU algorithms
- Surfaces – actual meshes
- Segments – identifying voxels as groups
- ISOSurfaces – rendered at a threshold

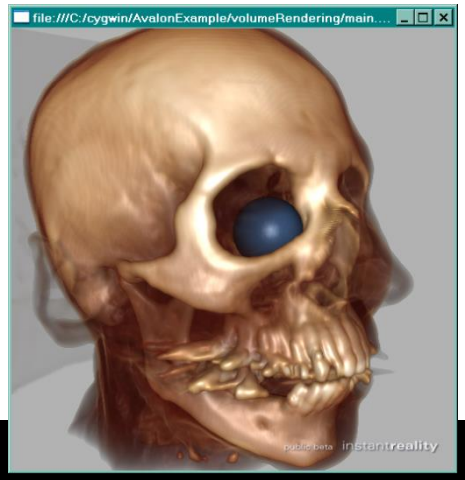


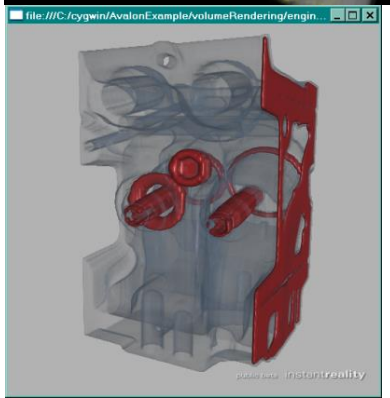
Reproducibility

Extensible 3D (X3D): A robust, cross-platform scene graph for Volume Rendering + Informatics by considering:

- ***Representation***
- ***Implementation***
- ***Interaction***
- ***Integration***





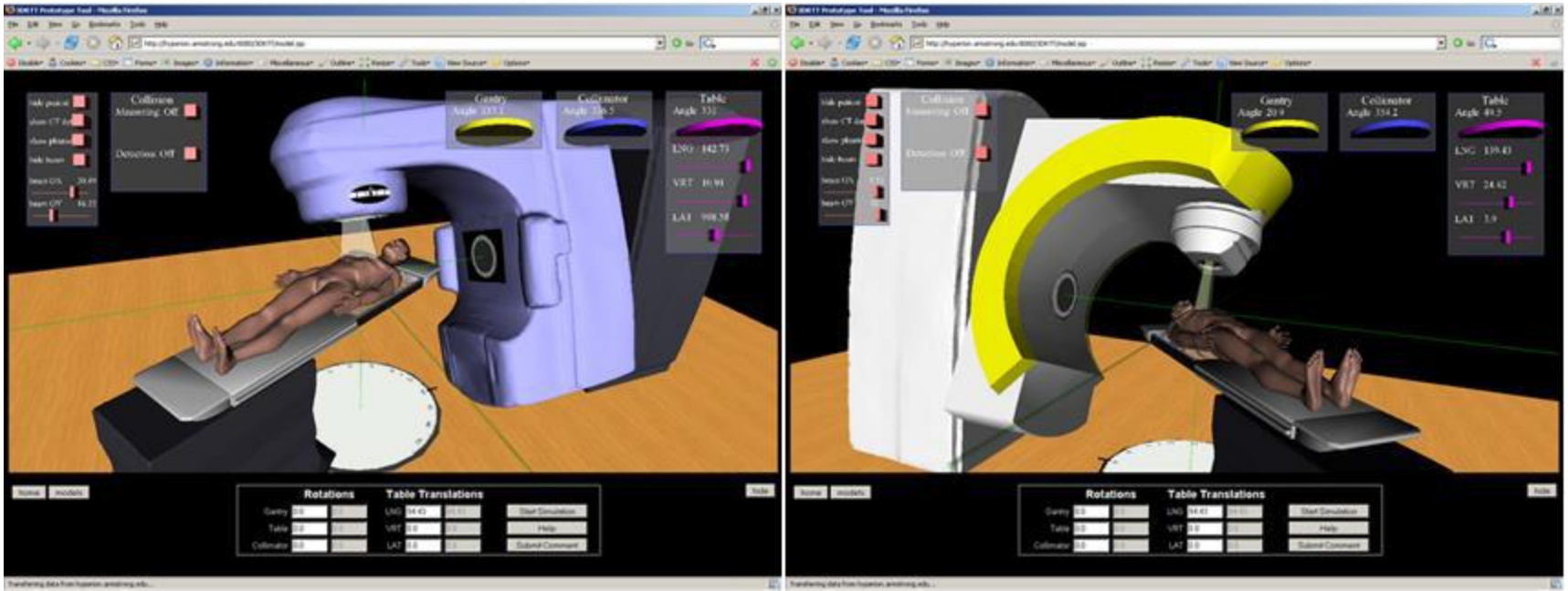


Impact & Requirements

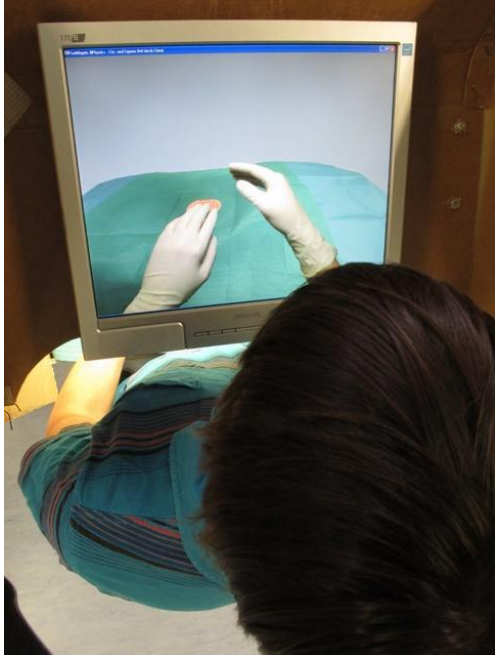
- Other Use Cases for scan data
  - Training & simulators
  - Web Publishing
  - 3D Printing
  - …
- Metadata Requirements
  - Represent links to ontologies, identifiers
  - Represent links to patient data bases
  - Provenance of volume data
    - Scan type
    - Processing algorithms
    - Visualization mappings
    - …

Felix Hamza-Lup, Armstrong State

- Radiation Therapy: 3drtt.org
- Accurate Treatment Simulation & Planning
- Patient-specific CT shells



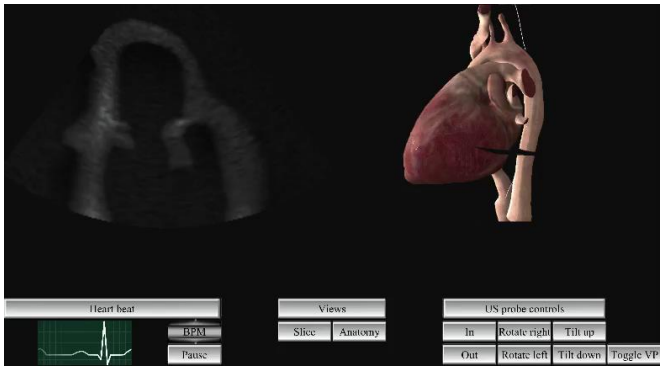
Tim Coles, CSIRO

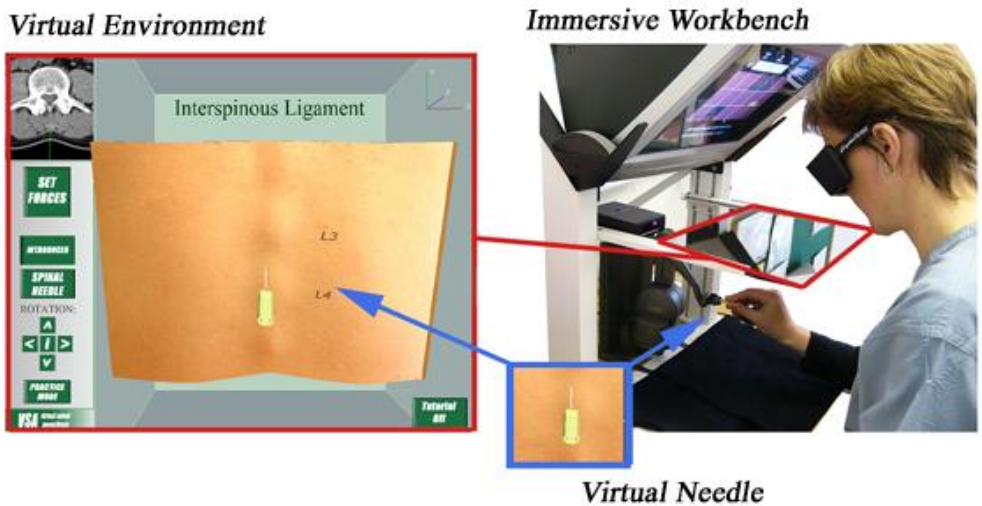


- w/ Nigel John on Medical Simulators: ‘Tiered training’ across platforms
- Haptics:
  - Palpation
  - visceral needle puncture procedures
- Simulated ultrasound guidance

Tommy Forsell (SenseGraphics)

- [H3D.org](H3D.org) : X3D + Python, ECMAScript, C++
- Rigid Body Physics
- OpenGL rendering
- Chai3D haptics renderer

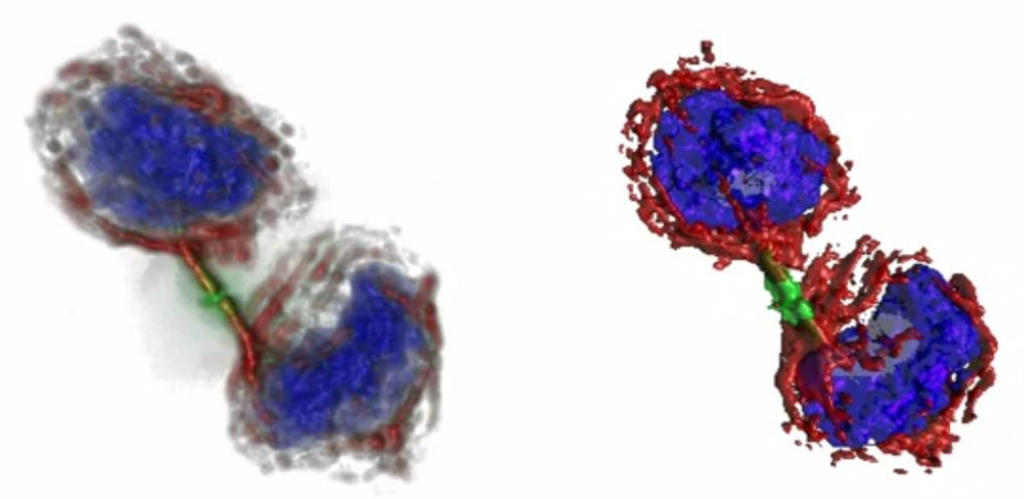




SenseGraphics

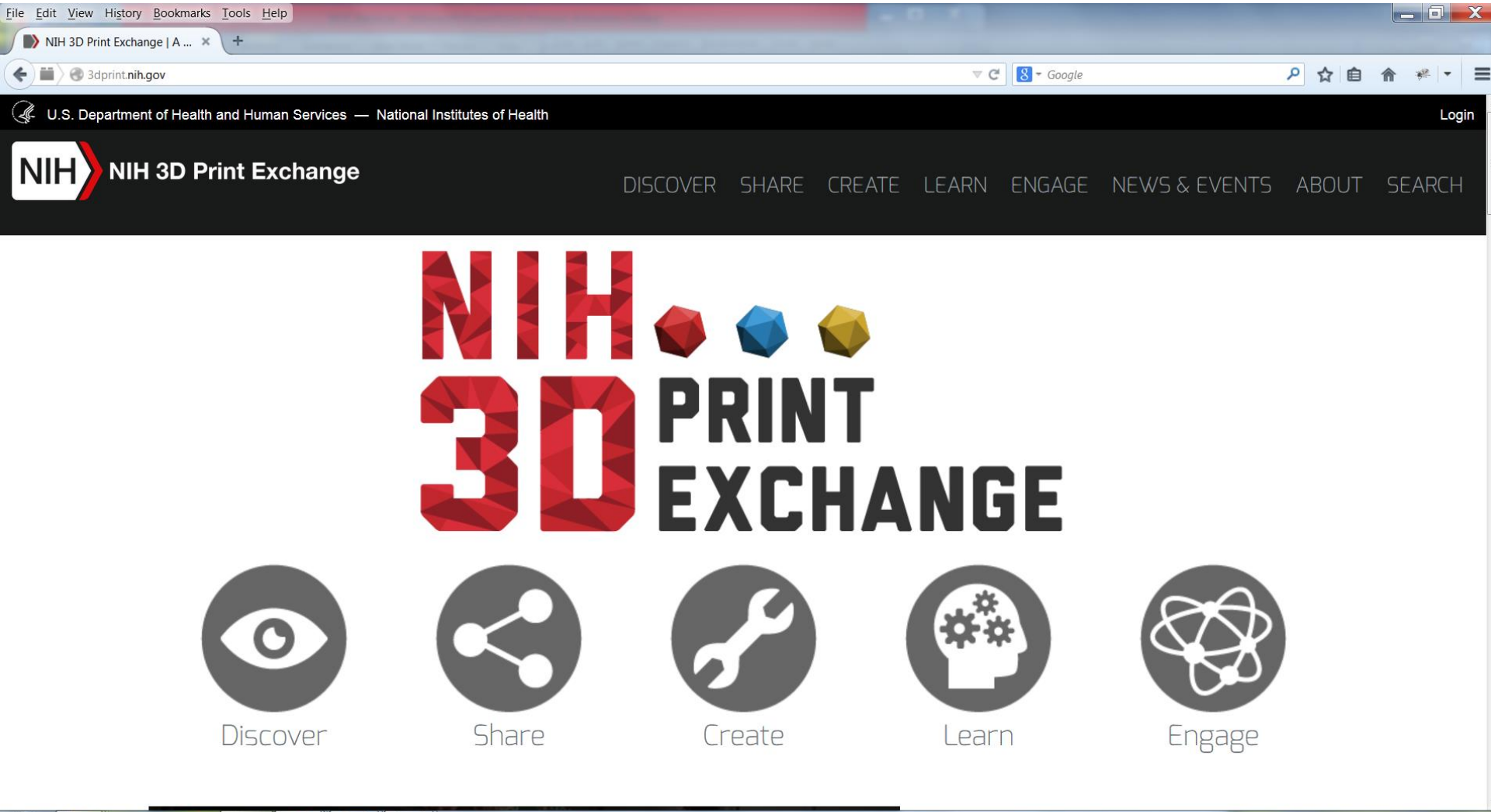
Abhijit Guarjapadhye, VT, Stanford

- Cell Imaging Library: *www.cellimagelibrary.org*
  - Multi-channel microscopy
  - Segmentation
  - Volume Rendering
  - Surface Rendering



- X3D examples:
  - http://metagrid2.sv.vt.edu/~abhijitg/CIL%20html/3d_cil.htm
  - https://survey.vt.edu/survey/entry.jsp?id=1355866408333

3dprint.nih.gov



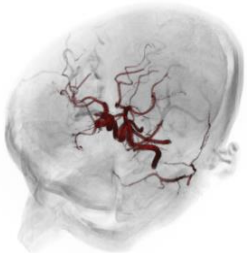
ISO/IEC X3D 3.3 Volume Rendering

- Composable Render Styles covering the state of the art
  - Formalizes parameters and transfer functions for the ***Greatest Common Denominator***

  Of 3D rendering & blending:
    - BoundaryEnhancementVolumeStyle
    - CartoonVolumeStyle
    - ComposedVolumeStyle
    - EdgeEnhancementVolumeStyle
    - OpacityMapVolumeStyle
    - ProjectionVolumeStyle
    - ShadedVolumeStyle
    - SilhouetteEnhancementVolumeStyle
    - ToneMappedVolumeStyle

Opacity Map Silhouette Cartoon

- Assign different RenderStyles to different segments, blend two volumes:
  - BlendedVolumeStyle
  - SegmentedVolumeData
  - IsoSurfaceVolumeData



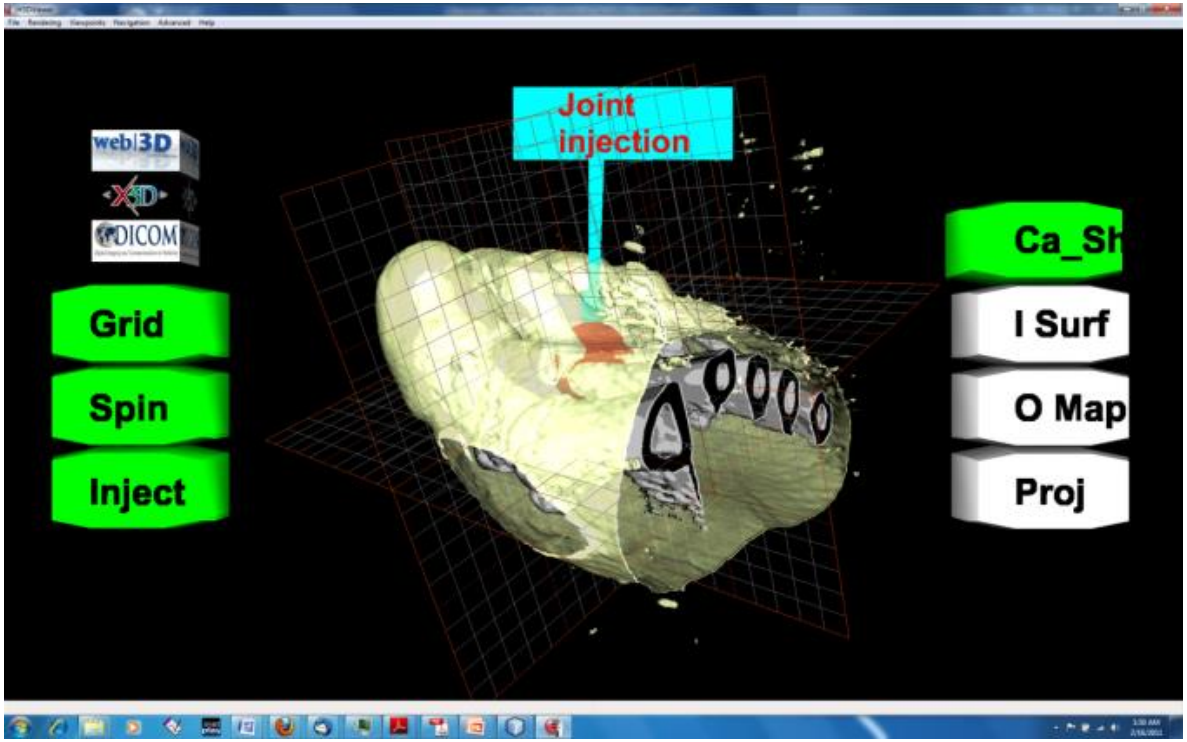
- Clipping Planes are already specified in X3D 3.2 Rendering Component!

ISO Medical Interchange Profile

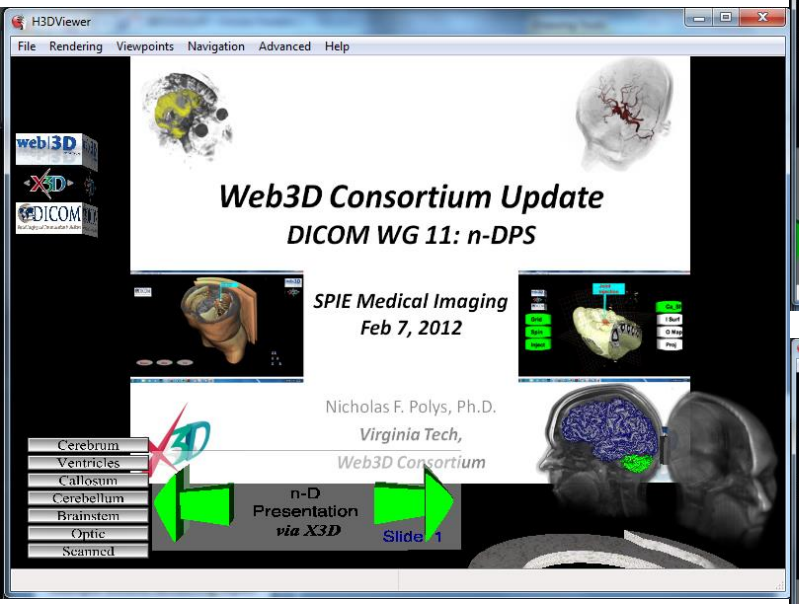
Minimal X3D scene graph node set to meet DICOM requirements:

Includes polygon, line and point rendering; metadata on any node

- Core
- Time
- Networking
- Grouping
- Rendering
- Shape
- Geometry3D
- Geometry2D
- Text
- Lighting
- Texturing
- Interpolation
- Navigation
- Environmental effects
- Event utilities
- Texturing3D
- Volume rendering



X3D Presentation Demo

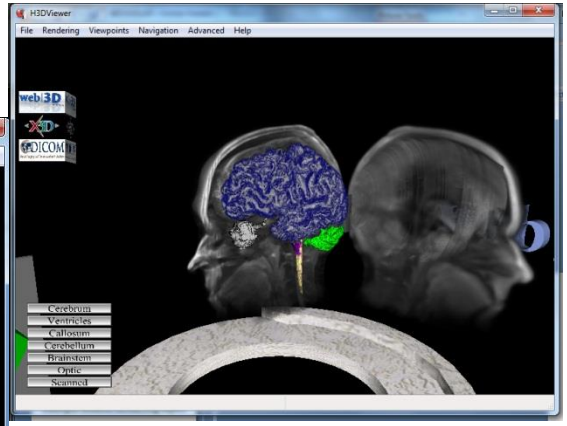


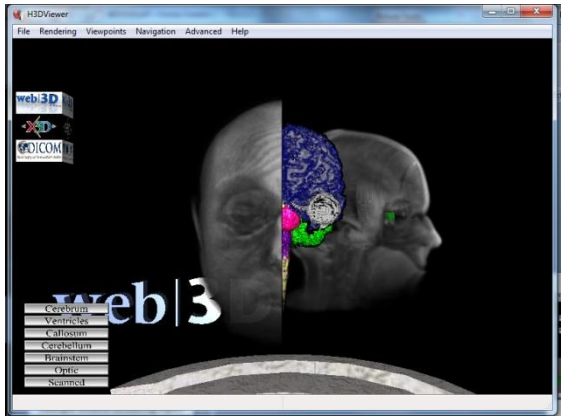
Web3D Consortium Update

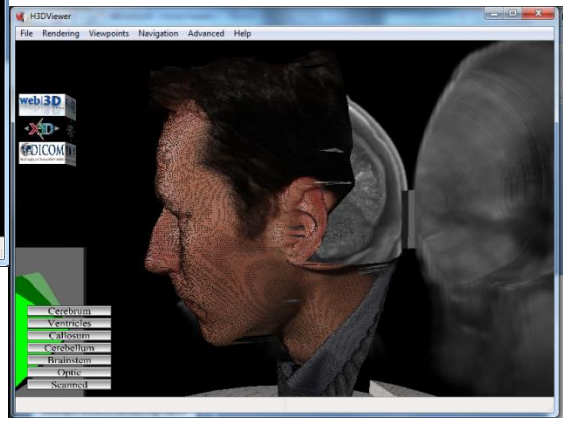
DICOM WG 11: n-DPS

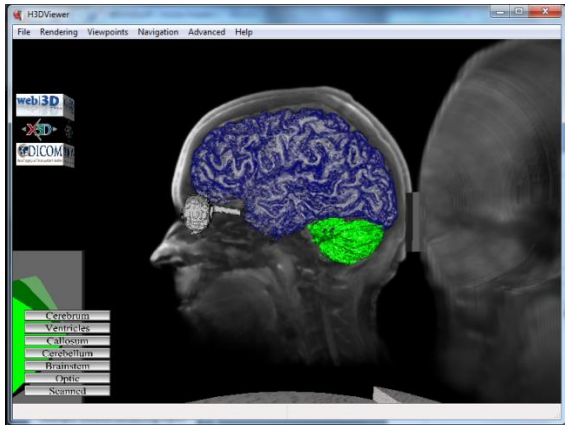
SPIE Medical Imaging
Feb 7, 2012

Nicholas F. Polys, Ph.D.
Virginia Tech,
Web3D Consortium









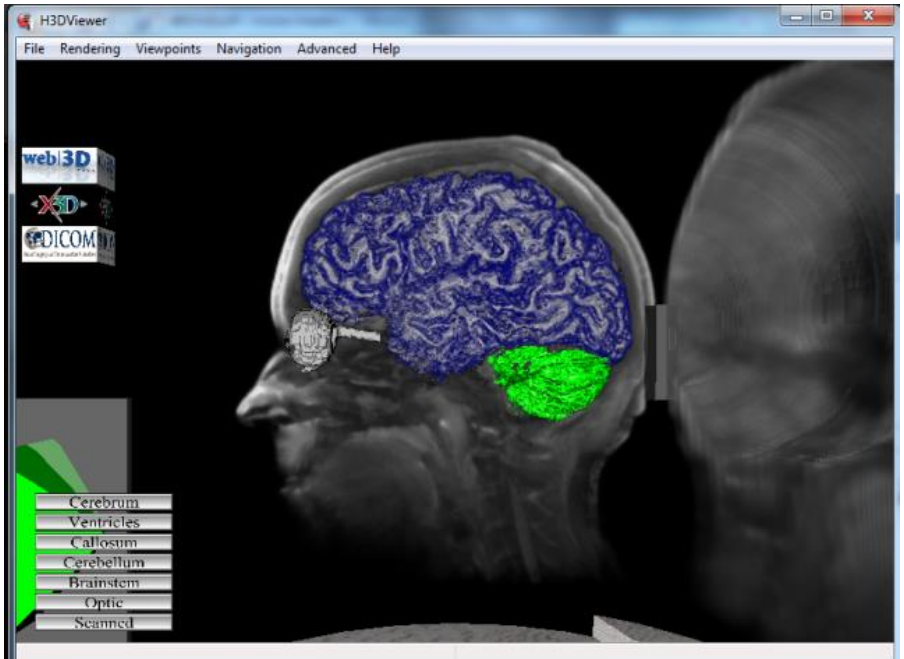
Screenshots

Nicholas Polys, Andy Wood, Abhijit Gurjarpadhye
Virginia Tech

Example Volume Rendering Styles

(Head MRI, XML encoding)

```
<Transform DEF='backdrop' >
    <VolumeData dimensions='.75 1 1' >
        <ImageTexture3D containerField="voxels" url='"./Segments/masked-vispart.nrrd"'/>
        <OpacityMapVolumeStyle />
    </VolumeData>
</Transform>
```



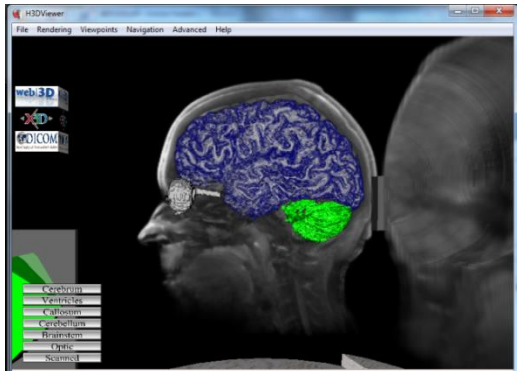
Example Volume Rendering Styles

(Head MRI, optic segment)

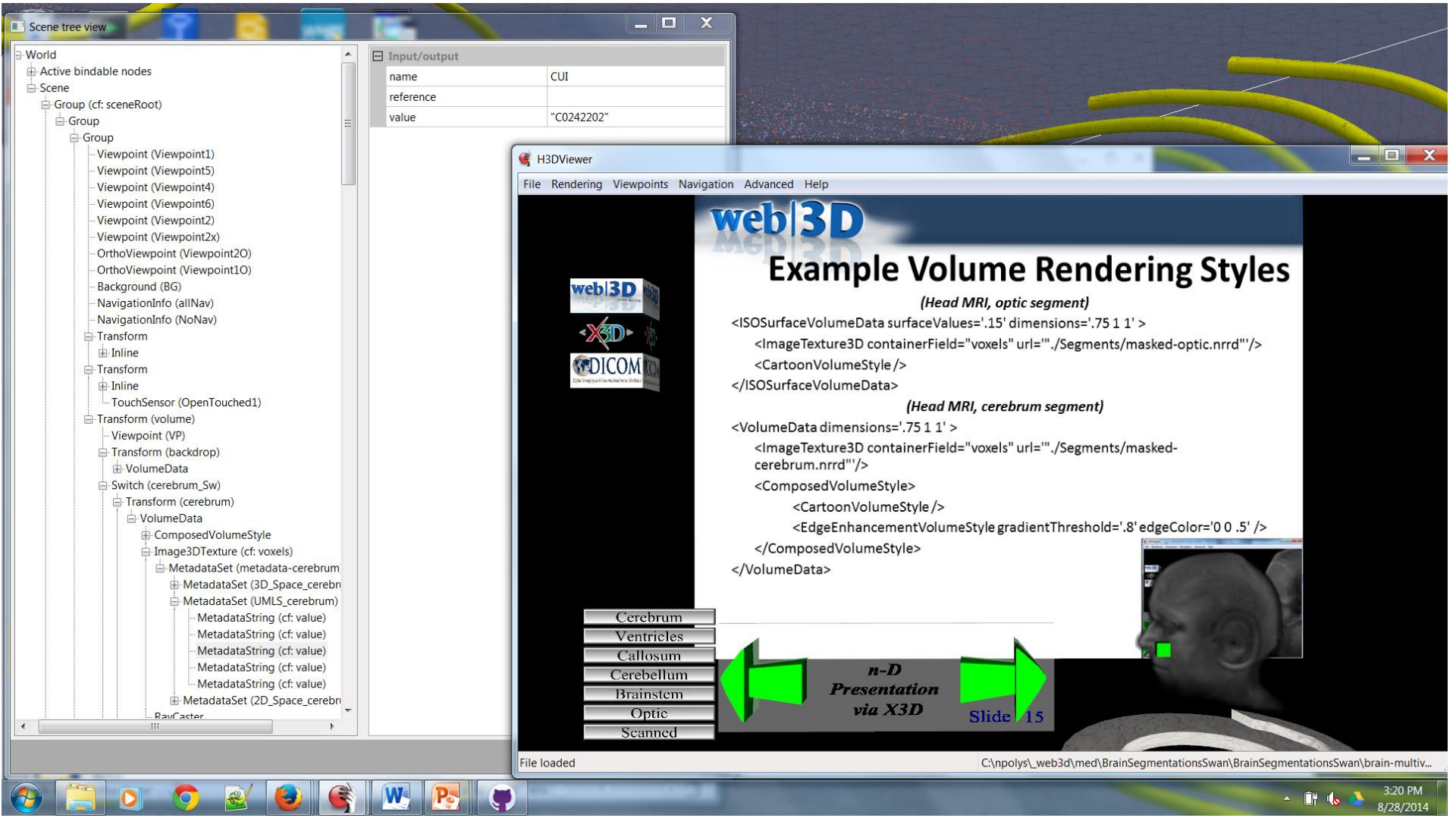
```
<ISOSurfaceVolumeData surfaceValues='.15' dimensions='.75 1 1' >
    <ImageTexture3D containerField="voxels" url='"./Segments/masked-optic.nrrd"'/>
    <CartoonVolumeStyle />
</ISOSurfaceVolumeData>
```

(Head MRI, cerebrum segment)

```
<VolumeData dimensions='.75 1 1' >
    <ImageTexture3D containerField="voxels" url='"./Segments/masked-
    cerebrum.nrrd"'/>
    <ComposedVolumeStyle>
        <CartoonVolumeStyle />
        <EdgeEnhancementVolumeStyle gradientThreshold='.8' edgeColor='0 0 .5' />
    </ComposedVolumeStyle>
</VolumeData>
```



Scene Graph Tree View



X3D Scene Graph Metadata

- ***MetadataSets can be a child of any node***
- Metadata types exist for all data types (name – value pairs)
- Metadata nodes include reference=“” attribute
- Thus, multiple MetadataSets / namespaces can be assigned to one node

X3D Scene Graph

Format and API above rendering libraries:

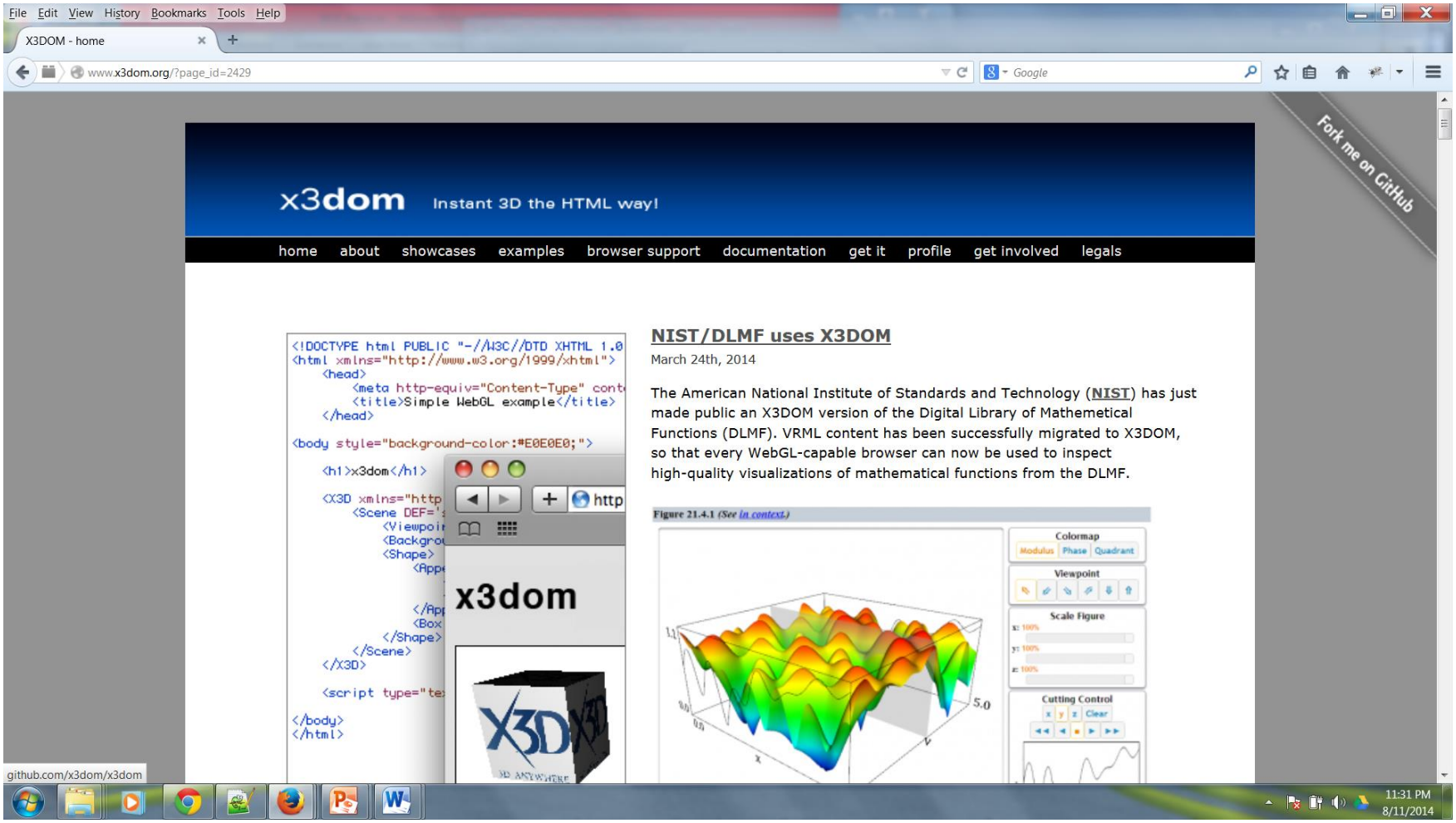
- Scene access to nodes, parameters and events for application-level control of 3D objects, viewpoints, lights and animations
- Can be implemented on top of any rendering library (e.g. OpenGL, DirectX, WebGL, POV-Ray) ; support for shaders, physics

ISO X3D Medical Interchange Profile node set is:

- Flexible & Expressive for the composition of data from web sources (URL/URIs)
- X3D Interchange + Volume Component + 3D Texturing Component + …

- **PUBLIC WIKI:**
  - **http://www.web3d.org/wiki/index.php/X3D_Medical**

X3DOM.org


File Edit View History Bookmarks Tools Help
X3DOM - home
www.x3dom.org/?page_id=2429
Google
Fork me on GitHub
x3dom
Instant 3D the HTML way!
home about showcases examples browser support documentation get it profile get involved legals
NIST/DLMF uses X3DOM
March 24th, 2014
The American National Institute of Standards and Technology (NIST) has just made public an X3DOM version of the Digital Library of Mathematical Functions (DLMF). VRML content has been successfully migrated to X3DOM, so that every WebGL-capable browser can now be used to inspect high-quality visualizations of mathematical functions from the DLMF.
Figure 21.4.1 (See in context.)
Colormap
Viewpoint
Scale Figure
Cutting Control
x3dom
github.com/x3dom/x3dom
11:31 PM
8/11/2014

X3DOM.org

- Shim for X3D + DOM integration in HTML5
- Renders via WebGL
- Liberal Open Source library, active community
  - Volume Rendering Component – active development of various ***RenderStyles***!
  - Clipping Plane support – released
  - MPR/CPR – demonstrated (VicomTech)

http://examples.x3dom.org/

Web3D Consortium

3D Solutions and Standards

http://Web3D.org/s2014/credits/fast-forward

Web3D.org Medical Working Group

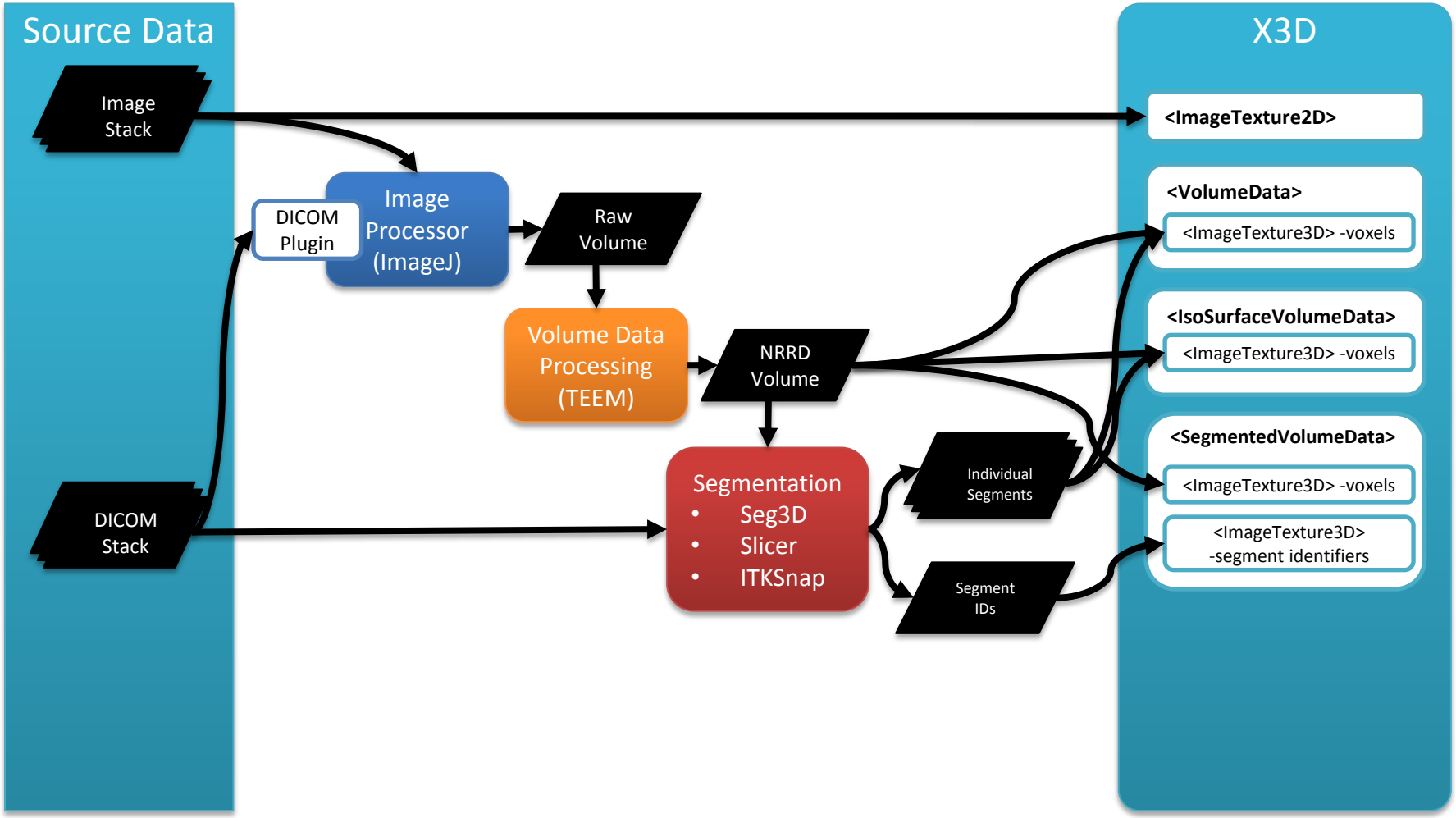
- ***Reproducible*** rendering and presentations for stakeholders throughout the healthcare enterprise
- An n-D Presentation state must be:
  - Structured and interactive virtual environment display of 2D & 3D medical imaging objects and time series
  - Platform-independent, royalty-free technology to enable vendor innovation
    - Handeld and immersive displays
    - Input devices
  - Lossless with provenance metadata and ontology references
  - Web-aware

web|3D CONSORTIUM

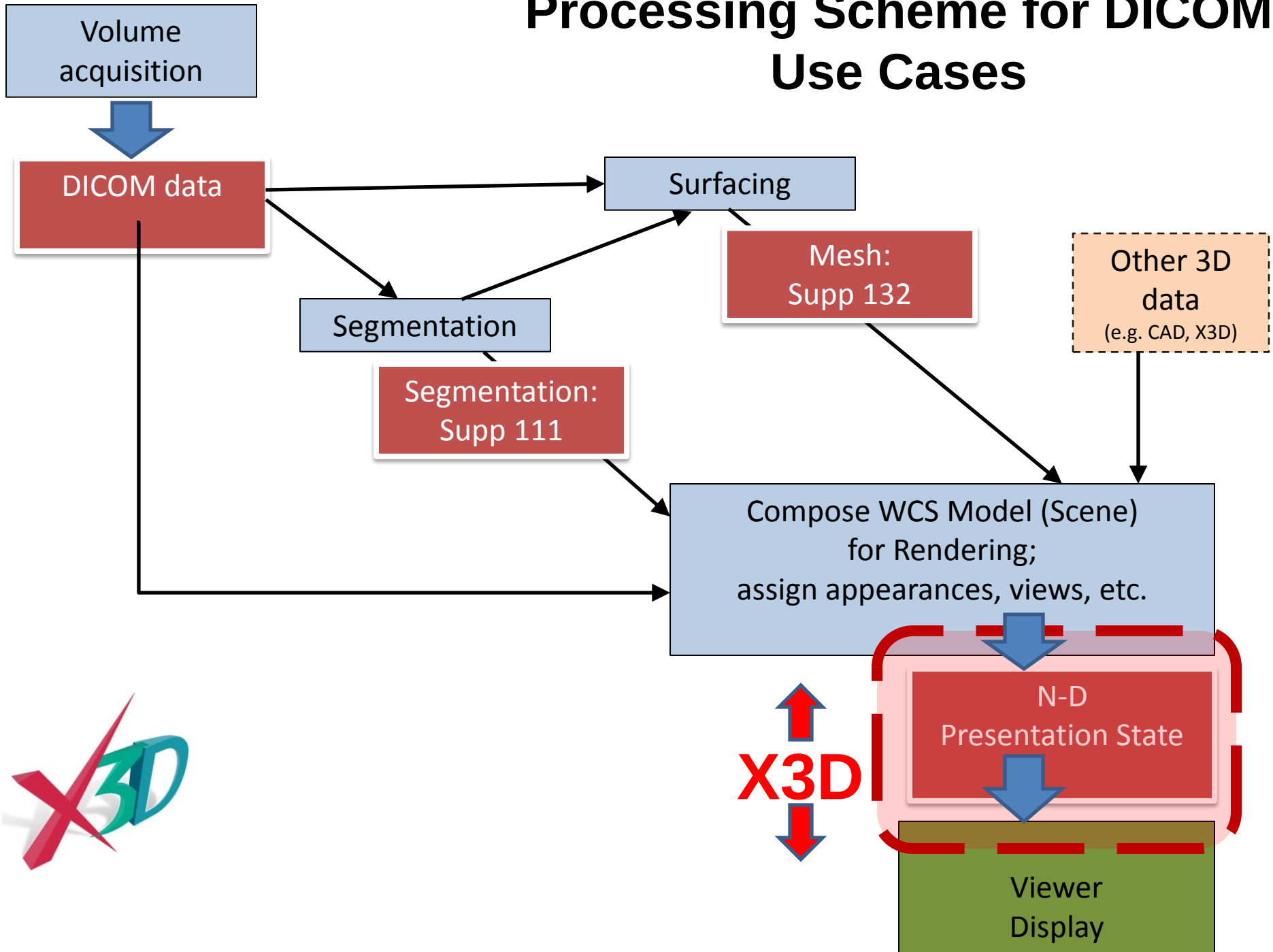
Acknowledgements

- TATRC
- Daniel Evestedt and Sebastian Ullrich (Sensegraphics)
- Don Brutzman (NPS)
- Nigel John U Wales Bangor, Richard Puk
- Yvonne Jung, Johannes Behr (Fraunhofer IGD)
- Luis Kabongo, John Congote (Vicomtech)

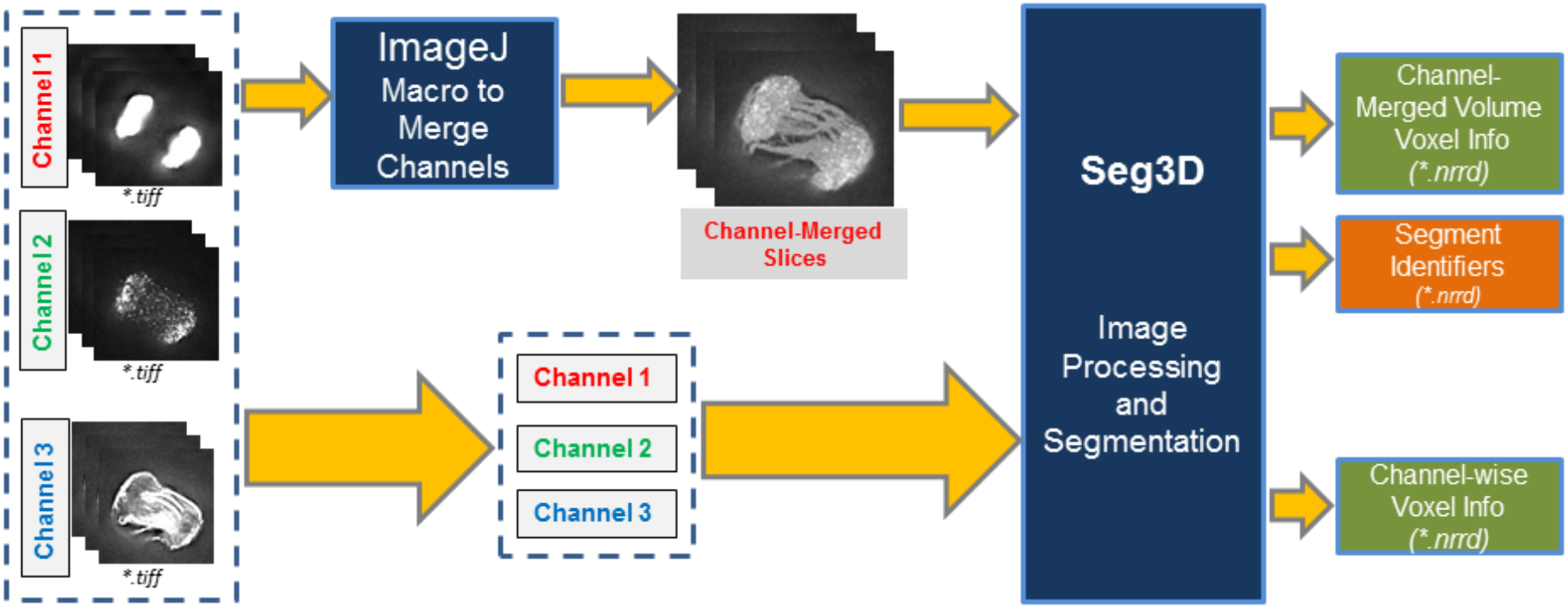
Volume Processing Pipelines



Processing Scheme for DICOM Use Cases



Multi-channel Microscopy



Fraunhofer IGD

- Liberal Open Source WebGL library for X3D and HTML5 integration
- X3DOM volume rendering component

… **X3DOM.ORG …**

- Other strong contributors around the world include VicomTech (Web3D Members)

See Also: the industrial strength *InstantReality.org*

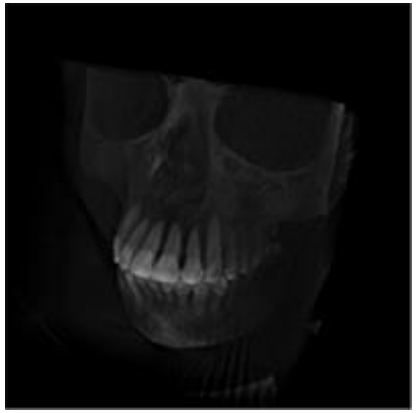
Supplemental Material

- Web3D 2013 Tutorial is online (excerpts below)
- See web3d.org Medical WG Public Wiki

Rendering a Volume: VolumeData Node

- Most basic volume rendering node in X3D
- Contains the voxels to be rendered and render styles to do so

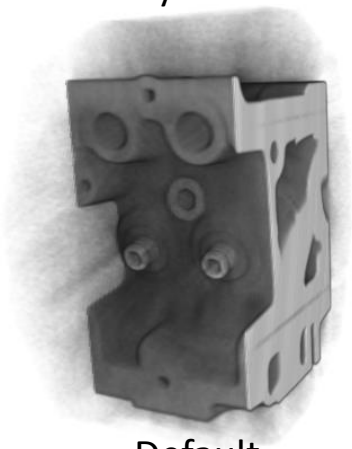
```
<VolumeData dimensions='1.28 1.28 1.0' >
        <!-- VolumeRenderStyle node here (optional) -->
        <ImageTexture3D containerField='voxels' url='  "path_to_dataset" '/>
</VolumeData>
```



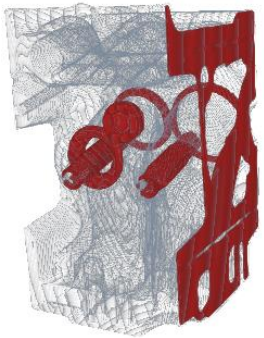
Opacity Map VolumeStyle

- The default style, the basis for all enhancement styles
- Has only one field, “transferFunction”
  - Two or three dimensional texture
  - One to four components

```
<OpacityMapVolumeStyle>
        <ImageTexture3D containerField='transferFunction' url='"engineTransferSchnitt.png"' />
</OpacityMapVolumeStyle>
```



Default



With Transfer Function

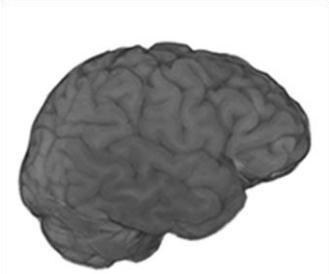
Projection VolumeStyle

- A raycasting technique
- Depending on the value of the “type” field, returns either the MAX, MIN, or AVERAGE of the voxel values along the ray
- If “intensityThreshold” is specified, returns the first local min/max above/below the threshol

```
<ProjectionVolumeStyle type='MAX' enabled='true' intensityThreshold='0'
  containerField='renderStyle'/>
```

Per-Voxel VolumeStyles

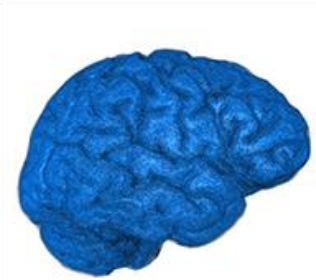
- View-Dependent
  - Opacity Map (default)
  - Enhancement Styles
    - Boundary, Edge, Silhouette
  - Cartoon
- Lighting-Dependent
  - Tone Map
  - Shaded



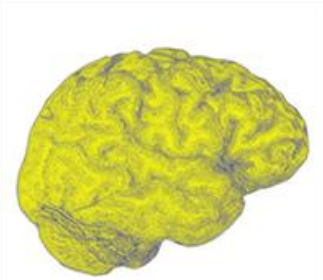
Opacity Map

Edge Enhanced

Cartoon



Shaded



Tone Map

Combining Styles: ComposedVolumeStyle

```
<ComposedVolumeStyle enabled='true' ordered='false' containerField='renderStyle'>
        <SilhouetteEnhancementVolumeStyle silhouetteBoundaryOpacity='1'
          silhouetteRetainedOpacity='.1' silhouetteSharpness='10' enabled='true'
          containerField='renderStyle'/>
        <EdgeEnhancementVolumeStyle edgeColor='.5 0 0' gradientThreshold='.8'
          enabled='true' containerField='renderStyle'/>
</ComposedVolumeStyle>
```

Rendering a Volume: IsoSurfaceVolumeData

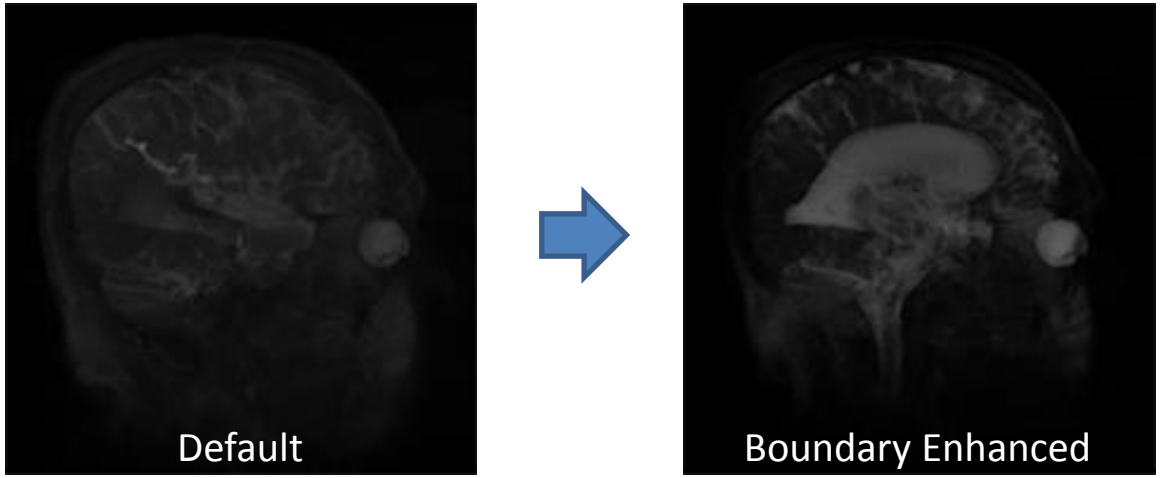
- Similar to the basic VolumeData node, but renders a surface across voxel gradients

```
<IsoSurfaceVolumeData dimensions='1.28 1.28 1.28‘ surfaceValues='.15'
 contourStepSize='0' surfaceTolerance='0' containerField='children'>
        <CartoonVolumeStyle colorSteps='32' />
        <ImageTexture3D containerField='voxels' url=' "skull.nrrd" '/>
</IsoSurfaceVolumeData>
```

Boundary Enhancement Style

- Modifies voxels based on how quickly their surface normals are changing:

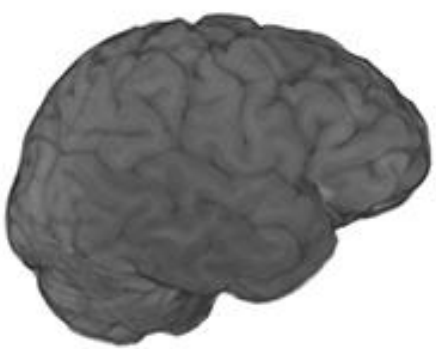
```
<BoundaryEnhancementVolumeStyle boundaryOpacity='0.9' opacityFactor='0.9'
 retainedOpacity='0.2'>
```



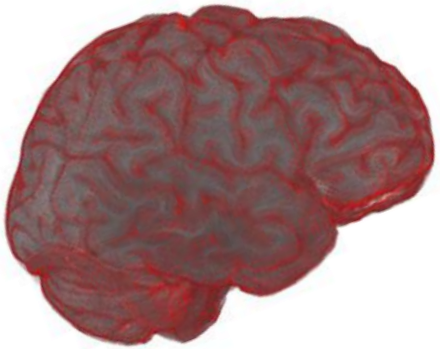
Edge Enhancement

- Voxels are colored based on how close to perpendicular their normal are to the view, outside of a threshold.
- Useful for surface features, not internal features.

```
<EdgeEnhancementVolumeStyle enabled='true' edgeColor=‘1 0 0 1‘
 gradientThreshold='0.4' containerField='renderStyle'/>
```



Default

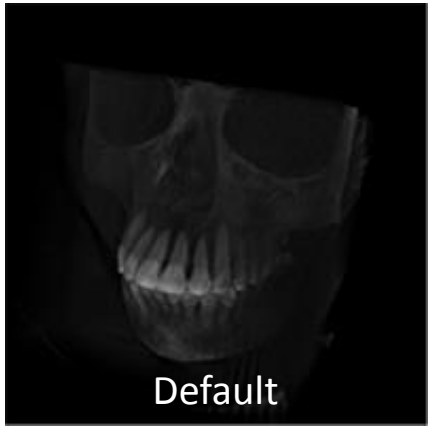


Edge Enhanced

Silhouette Enhancement

- Modifies the color and opacity of voxels based on their normal values
- Unlike edge enhancement, it can be used to reveal internal features

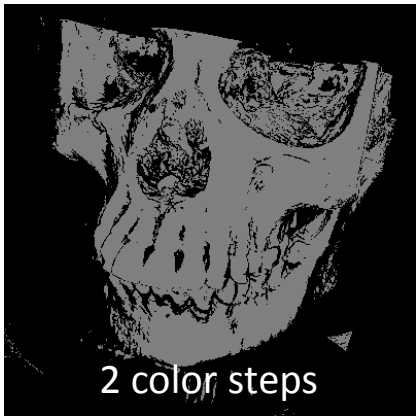
```
<SilhouetteEnhancementVolumeStyle silhouetteBoundaryOpacity='1'
 silhouetteRetainedOpacity='.5' silhouetteSharpness='10' enabled='true'
 containerField='renderStyle'/>
```

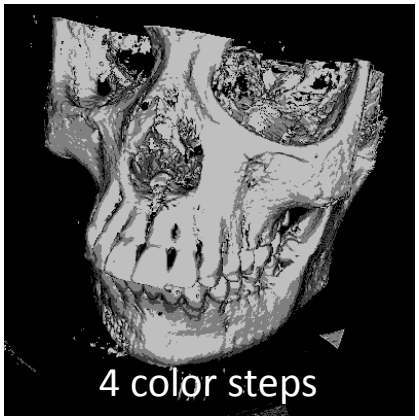


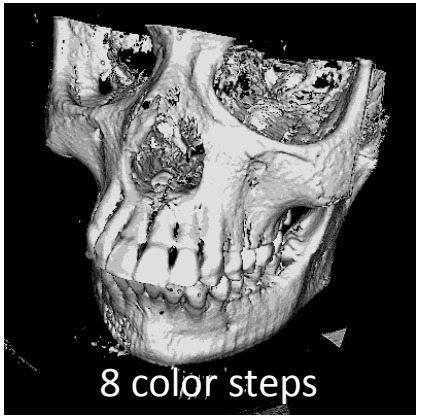
Cartoon VolumeStyle

- Renders voxels based on the normal value as one of a specified number of color steps between an orthogonal (plane surface) color and parallel color:

```
<CartoonVolumeStyle enabled='true' colorSteps='4' orthogonalColor='1 1 1 1'
 parallelColor='0 0 0 1' containerField='renderStyle'/>
```





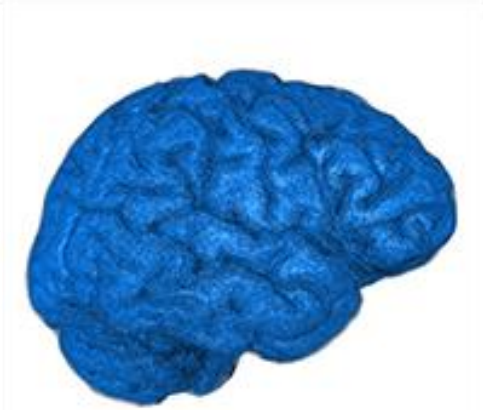


Shaded VolumeStyle

- Voxel appearance is controlled by a material node, similar to normal geometry (relative to light source)
- Can be computationally expensive

```
<ShadedVolumeStyle lighting='true' shadows='true' enabled='true'
  phaseFunction='Henyey-Greenstein' containerField='renderStyle'>
            <Material ambientIntensity='0.8' diffuseColor='0 .5 1‘ shininess='0.08'
             specularColor='1 1 1'/>
</ShadedVolumeStyle>
```

Default

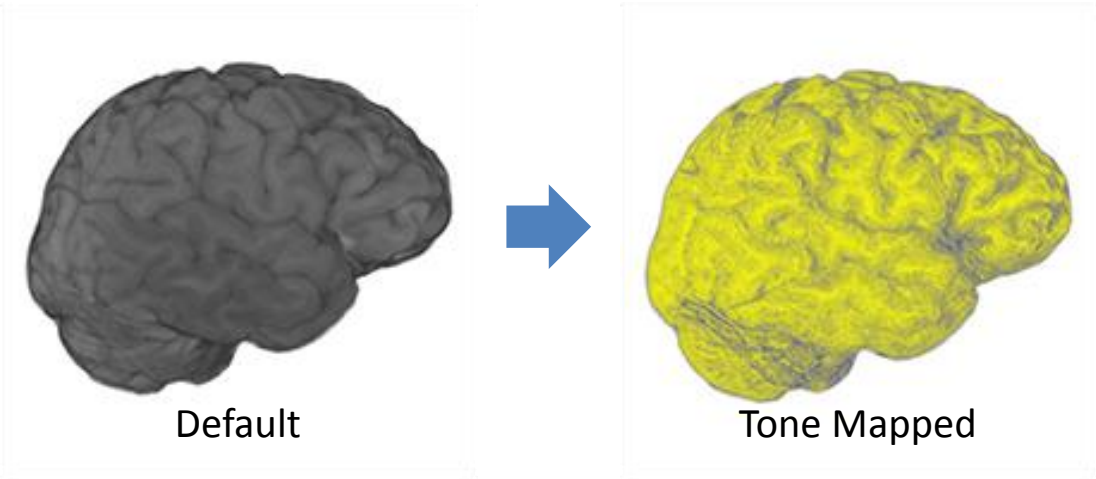


Shaded

Tone Mapped VolumeStyle

- Uses the Gooch shading model to color voxels based on their orientations relative to a light source, between a warm (facing light) and cool (facing away) color

```
<ToneMappedVolumeStyle warmColor='0 0 1 0' coolColor='1 1 0 0' />
```

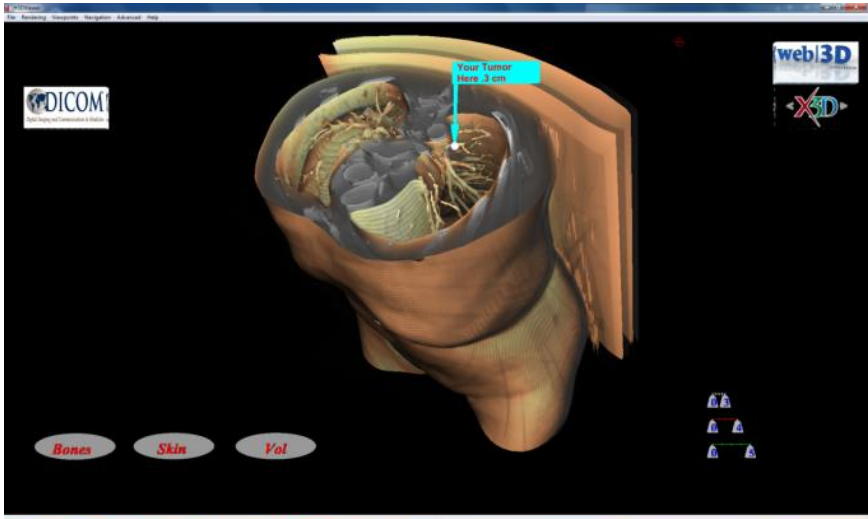


Online Videos & Examples

- Web Video summary:
  - *Extensible 3D (X3D) Volume Rendering*
    - https://snoid.sv.vt.edu/medical/X3DVolumes/videos/VolumeVis-X3D-collected.mp4 (65 mb)
- X3D Examples
  - http://www.web3d.org/x3d/content/examples/Basic/VolumeRendering/index.html
- For other other Videos, Images and Scenes using the VolumeData and VolumeRenderStyles of X3D 3.3 Clause 41, please visit:
  - https://snoid.sv.vt.edu/medical/X3DVolumes/

Volume Processing and Presentation Tools

- **Data**
  - Sample xxxxn.dcm
  - X3D Content Examples http://www.web3d.org/x3d/content/examples/Basic/VolumeRendering/index.html
  - Volvis.org
  - http://www.osirix-viewer.com/datasets/
    - Warning: some are compressed w/ jpg2000 !
- **Tools**
  - ImageJ : http://rsbweb.nih.gov/ij/
    - Plugins: DICOM reader, DICOM header inspector
  - Seg3D.org
  - Slicer.org
  - ITK-Snap
  - X3D-Edit 3.3
- **Viewers**
  - H3D.org
  - InstantReality.org
  - MedX3DOM



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