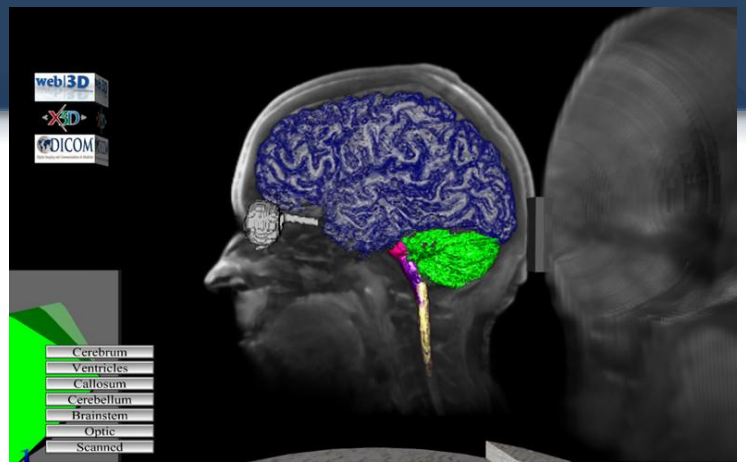
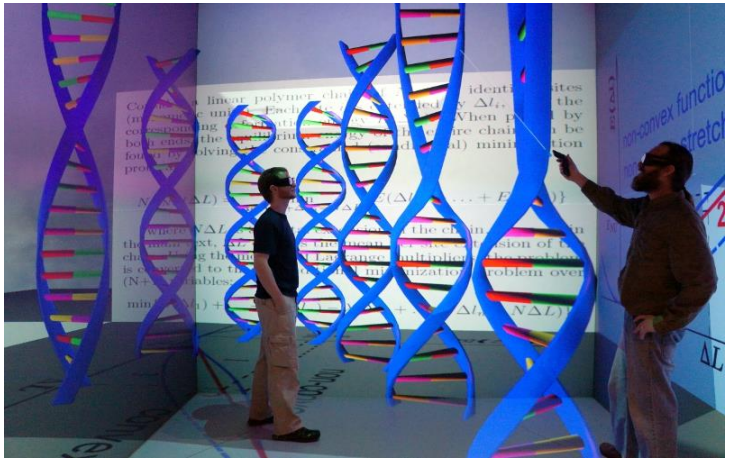
Medical and Volume Visualization

SIGGRAPH 2015





Nicholas Polys, PhD
& Michael Aratow, MD, FACEP
Web3D Consortium **www.web3d.org**
Medical WG Chairs

Ander Arbelaiz, Luis Kabongo, Aitor Moreno
Vicomtech-IK4

Darrell Hurt, Meaghan Coakley, James Terwitt-Drake
National Institute of Health (NIH)

Daniel Evestedt, Sebastian Ullrich
Sensegraphics

Update !

Web3D 2015 Annual Conference

- Sponsored by ACM SIGGRAPH
- in Cooperation with Web3D Consortium and Eurographics
- 20th Annual held in Heraklion, Crete June 2015
  - See papers @ siggraph.org and acm dl!
- Next year in Anaheim co-located with SIGGRAPH

Medical and Volume Visualization

- X3D highlights

- X3DOM (X3D + HTML5 + WebGL)

Consortium

- ***Content*** is King !
  - Author and deploy interactive 3D assets and environments with confidence, royalty-free
  - Required:
    Portability, Interoperability, Durability

- Not-for-profit, member-driven organization
- International community of creators, developers, and users building evolving over 20 years of graphics and web technologies
- Open Standards ratification (ISO/IEC)

Medical and Volume Visualization

The Web3D Consortium Medical Working Group is chartered to advance open 3D communication in the healthcare enterprise

- BOFs, workshops, and progress since 2008 when TATRC sparked the flame with ISO/IEC Volume Component in X3D

PUBLIC WIKI:

http://www.web3d.org/wiki/index.php/X3D_Medical

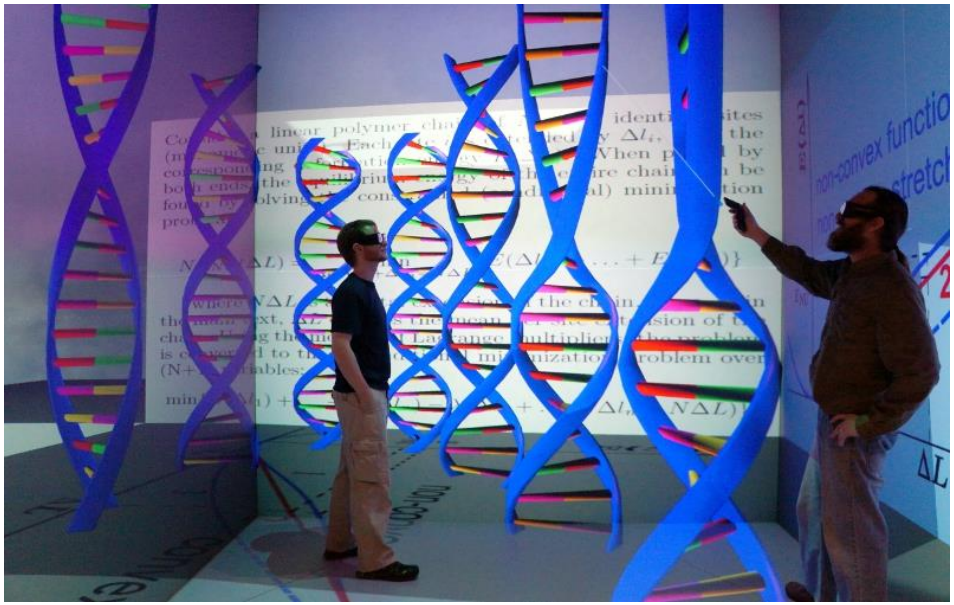
Web3D.org Medical Working Group

- ***Reproducible*** rendering and presentations for stakeholders throughout the healthcare enterprise (and at home):
  - Structured and interactive virtual environment display of 2D & 3D medical imaging objects and time series
  - Platform-independent, royalty-free technology to enable vendor innovation
    - Hand-held and immersive displays
    - Input devices
  - Lossless with provenance metadata and ontology references
  - Web-aware

Interactive 3D Data in Medicine

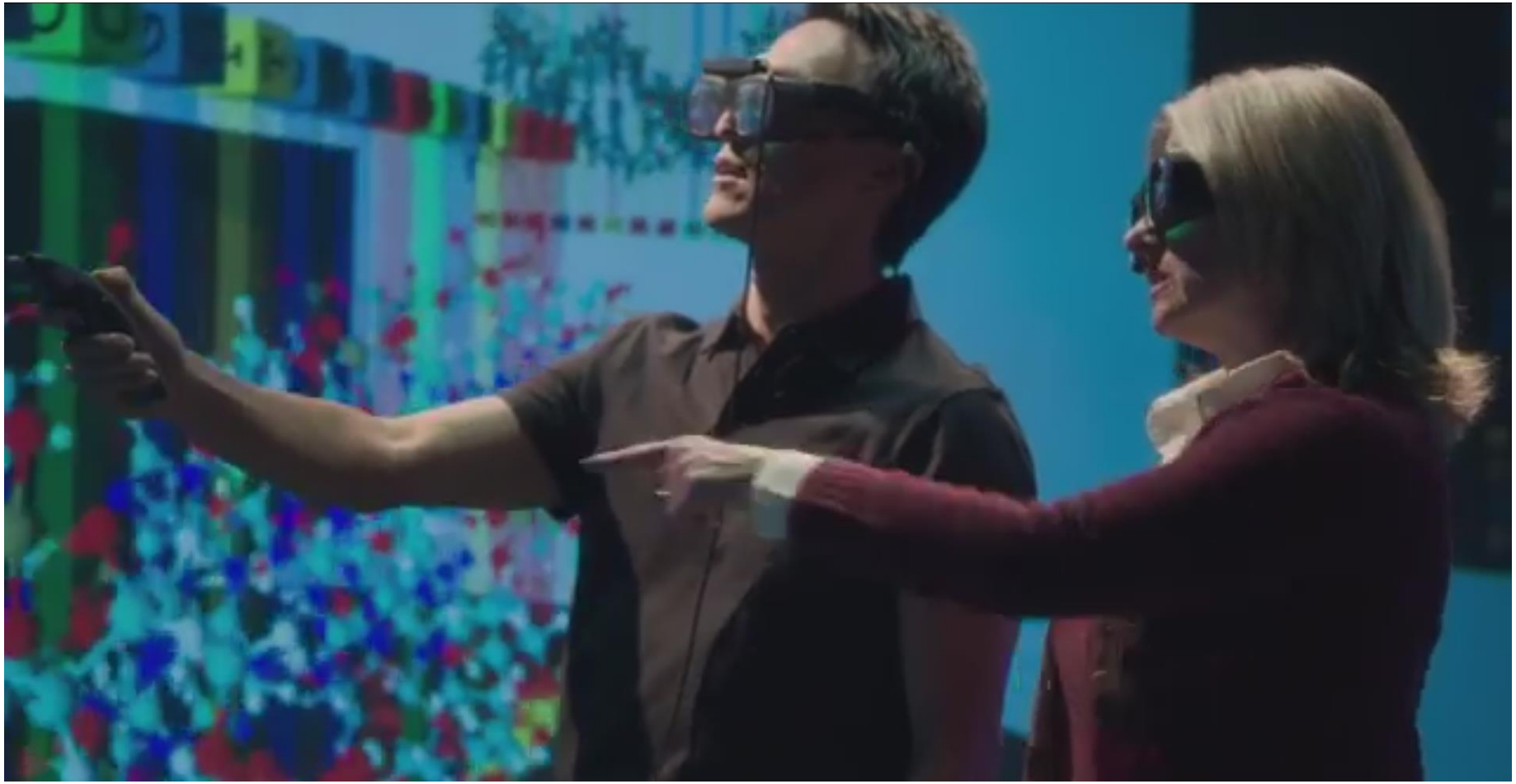
Many cross-platform applications demonstrated with the open graphics standard:

- Bioinformatics
- Molecular Dynamics
- Microscopy
- 3D Printing
- Imaging
- …



MPI Blast: Compute the Cure

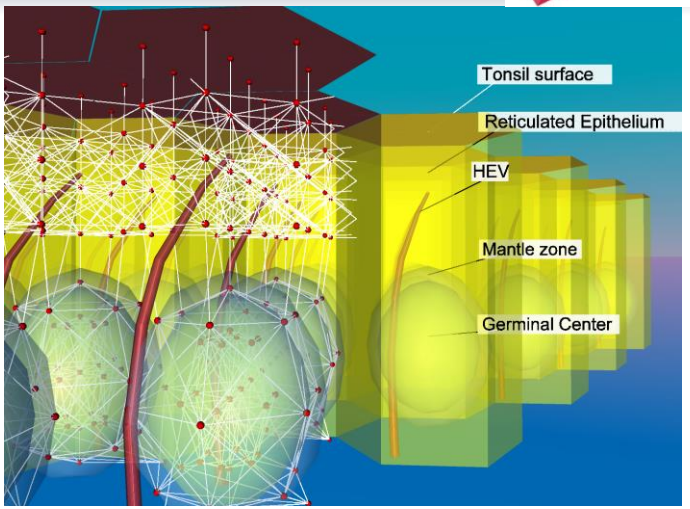
https://www.youtube.com/watch?v=7Zw8gKJXgI4

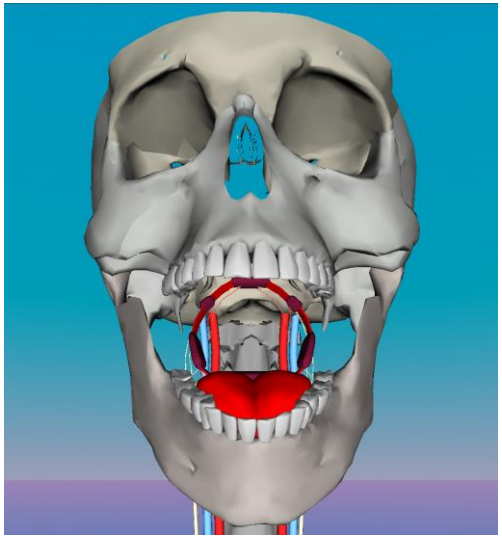


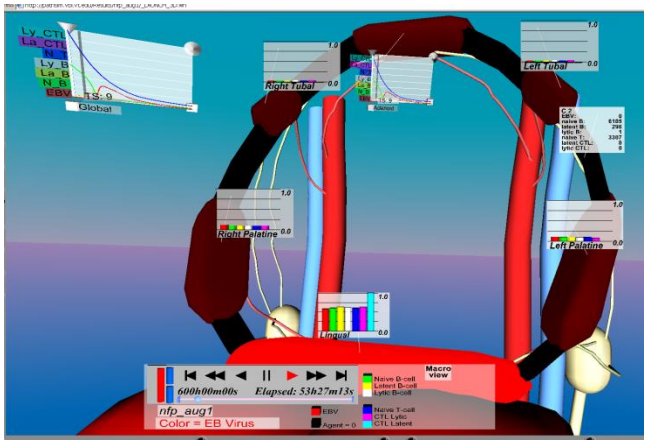
PathSim

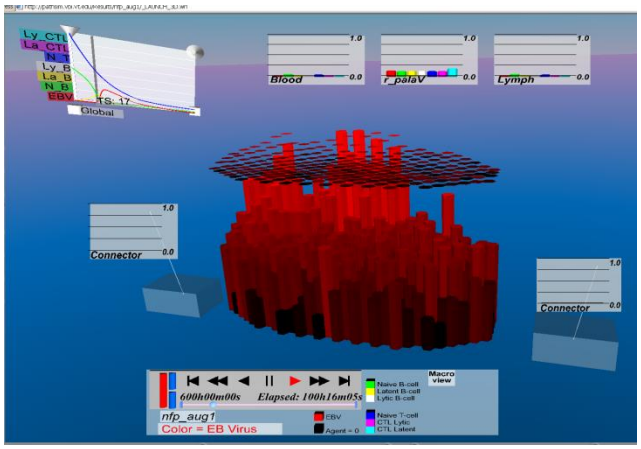
- EBV Agent-based simulation

http://scholar.lib.vt.edu/theses/available/etd-06152006-024611/unrestricted/PathSimv2.avi



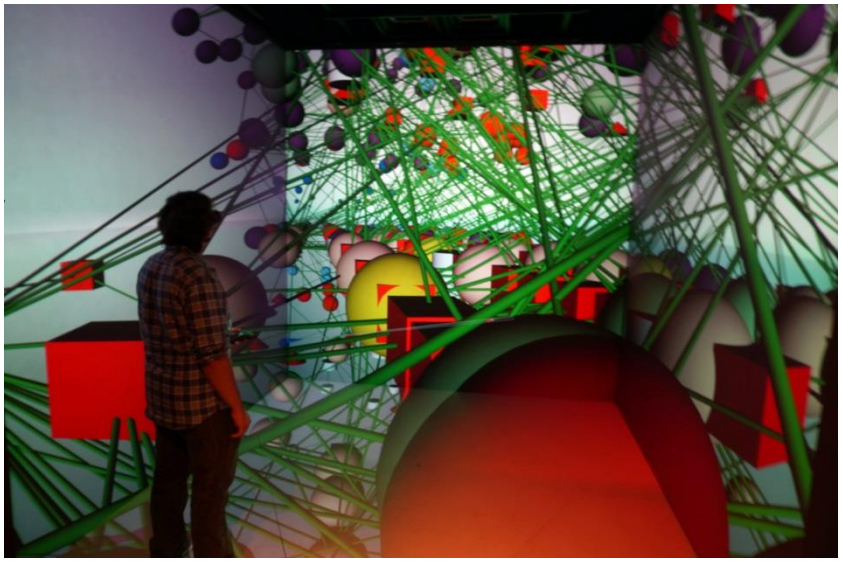


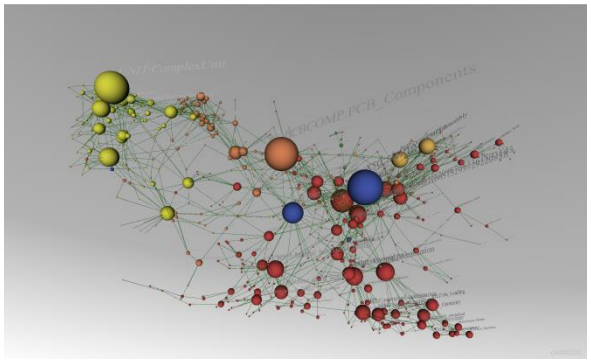




Shapiro, M., K. A. Duca, K. Lee, E. Delgado-Eckert, A.S. Jarrah, R. Laubenbacher, **N.F. Polys**, V. Hadinoto, D. Thorley-Lawson, (2008). "A Virtual Look at Epstein-Barr Virus Infection: Simulation Mechanism." Journal of Theoretical Biology **252**(4): 633-648.

BioPax Ontology Vis



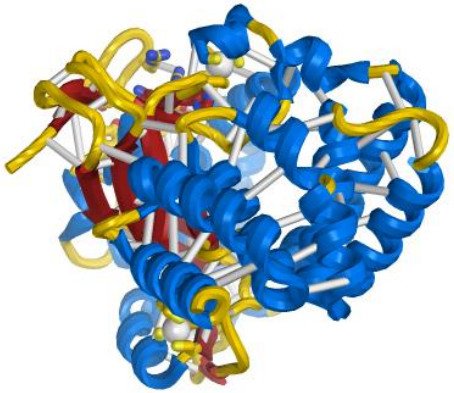


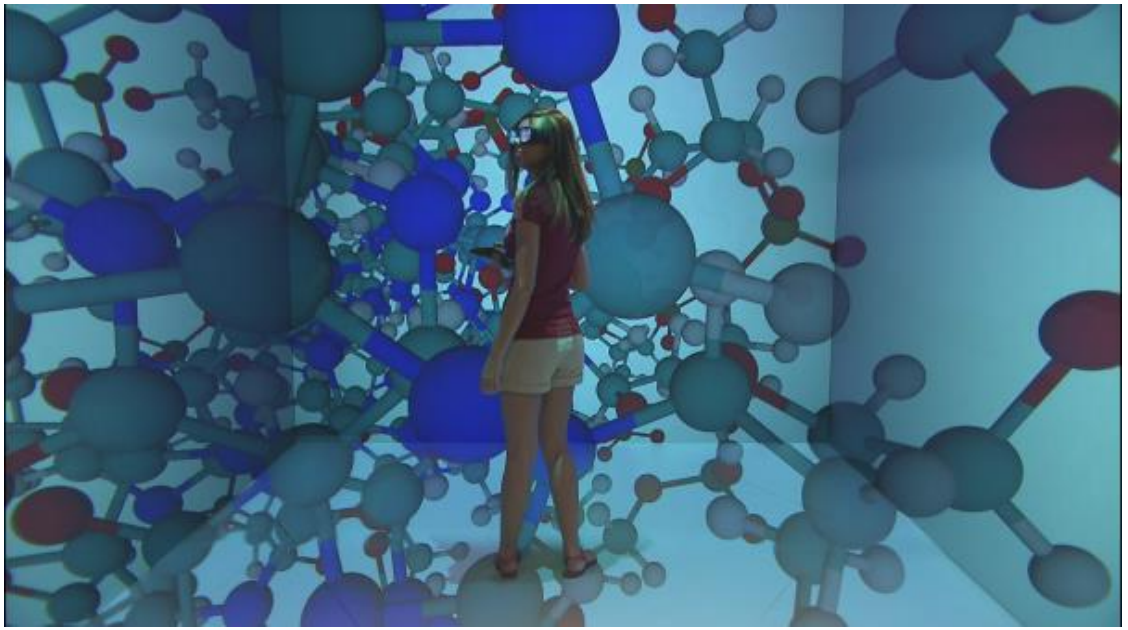
Peter J. Radics, **Nicholas F. Polys**, Shawn P. Neuman, and William H. Lund. "OSNAP! Introducing the open semantic network analysis platform". *Proceedings of Visualization and Data Analysis*, IS&T/SPIE Electronic Imaging; 2015.

Molecular Visualization

- Structures (e.g. PDB)
- Behavior (Simulation output to Chimera, VMD)

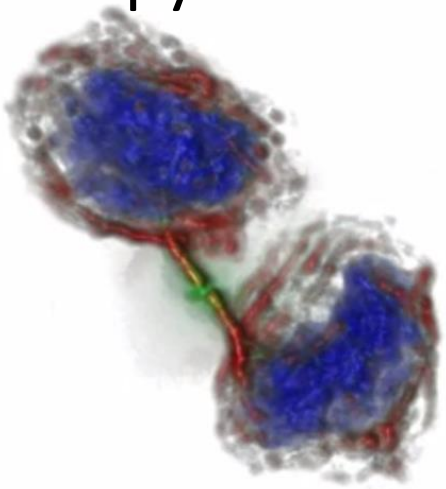
https://www.youtube.com/user/VTVisionarium/

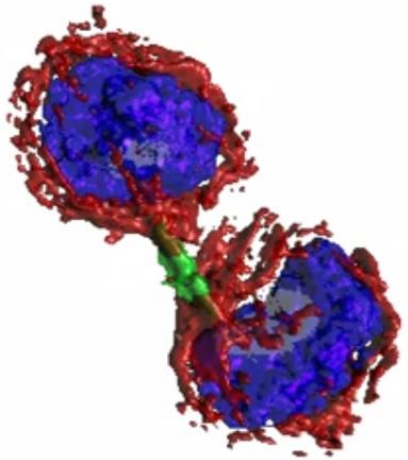




Cell Image Library

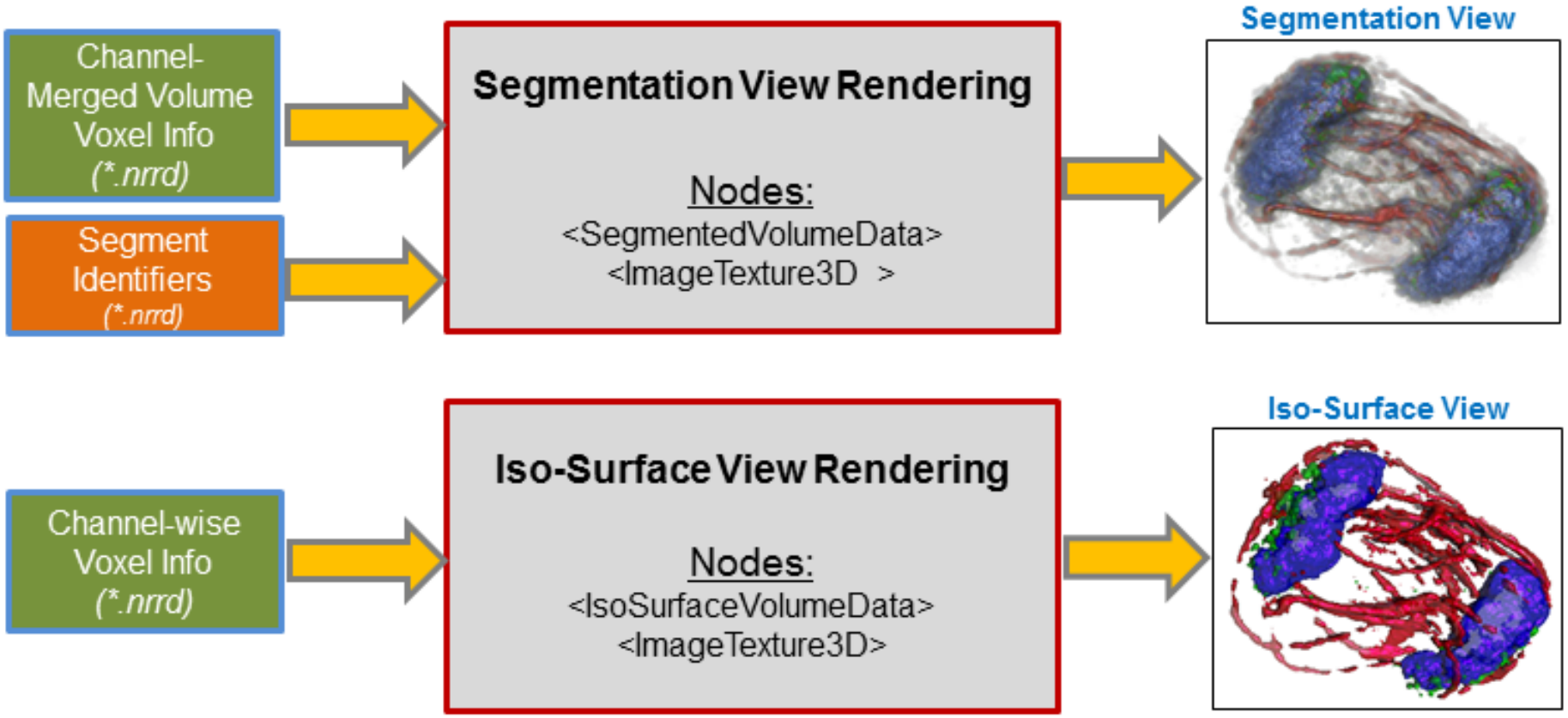
- Cell Imaging Library: *www.cellimagelibrary.org*
  - Multi-channel microscopy
  - Segmentation
  - Volume Rendering
  - Surface Rendering





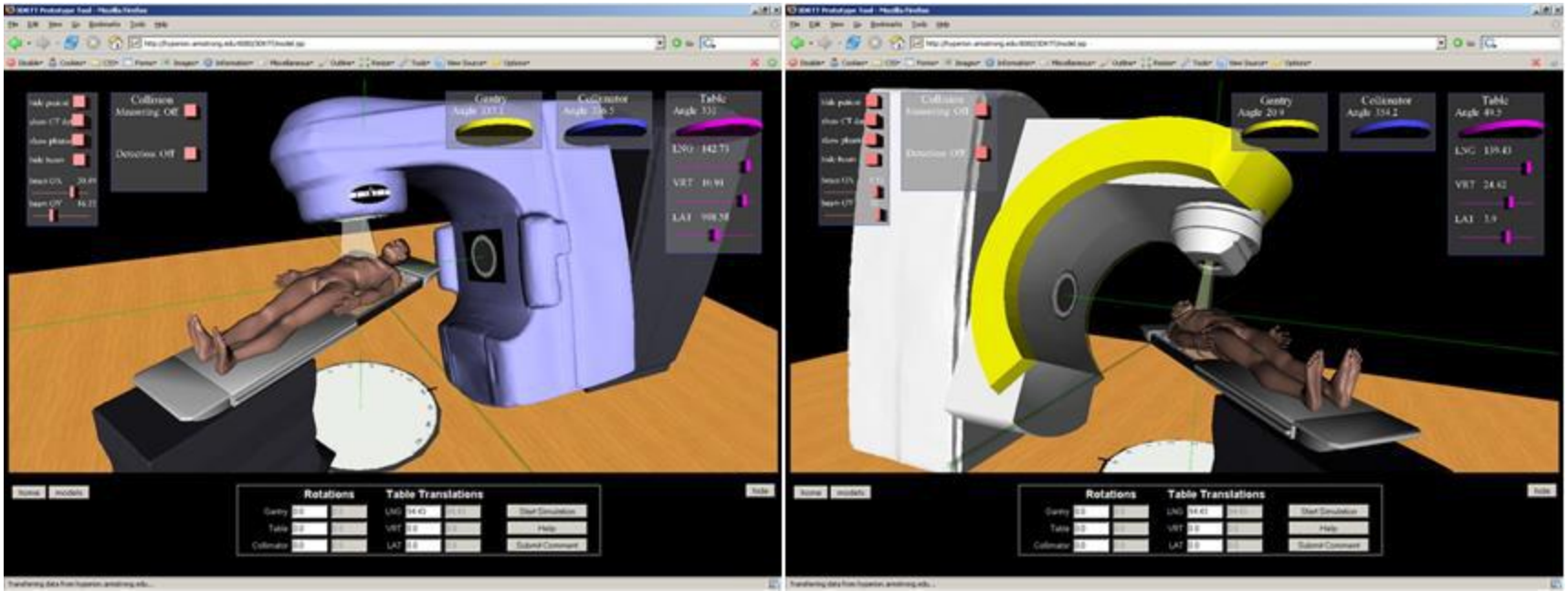
- X3D examples:
  - http://metagrid2.sv.vt.edu/~abhijitg/CIL%20html/3d_cil.htm
  - https://survey.vt.edu/survey/entry.jsp?id=1355866408333

Multi-channel Microscopy



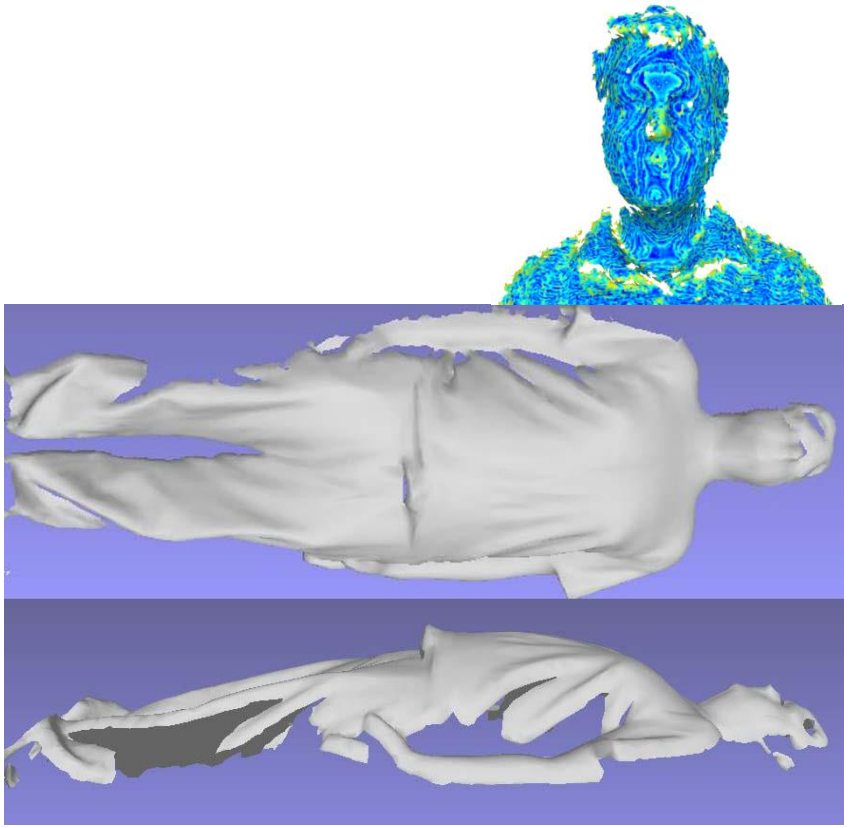
Felix Hamza-Lup, Armstrong State

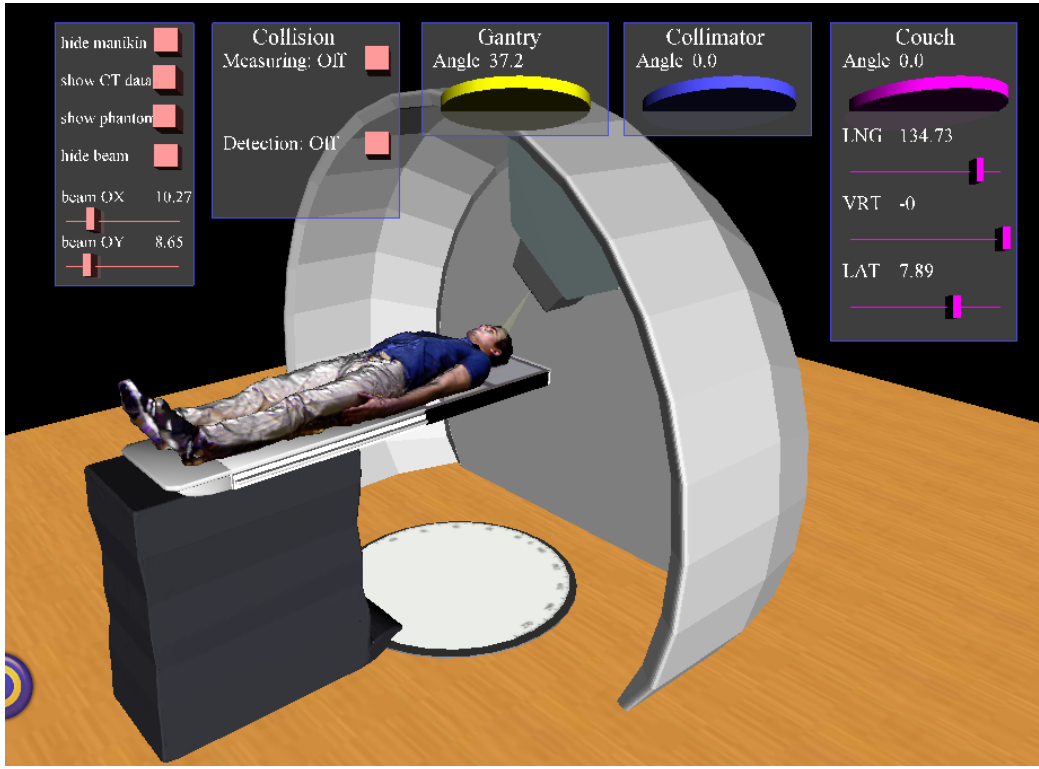
- Radiation Therapy: ***3drtt.org***
- Accurate Treatment Simulation & Planning
- Patient-specific shells



Evaluating Kinect Acquisitions

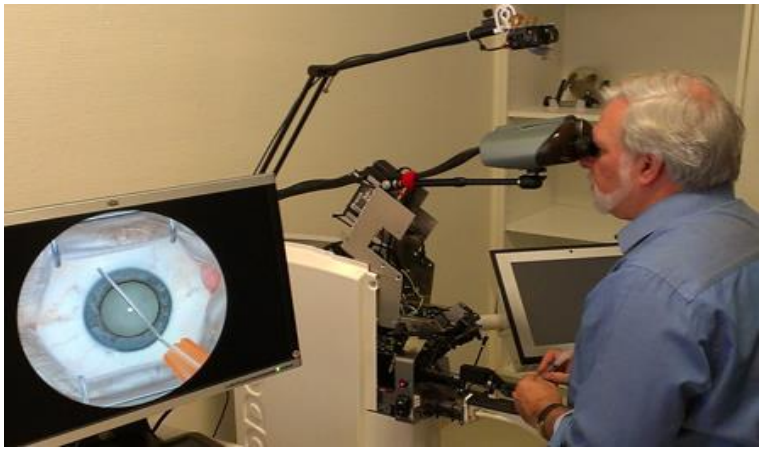
- Web3D 2015 paper!





Surgical Training

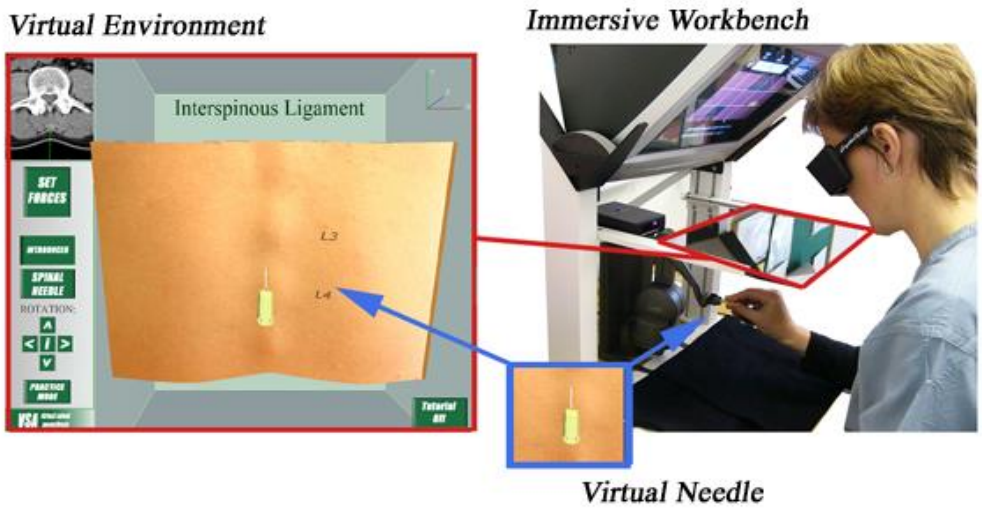
- HelpMeSee



  - H3D.org
  - SOFA

SenseGraphics

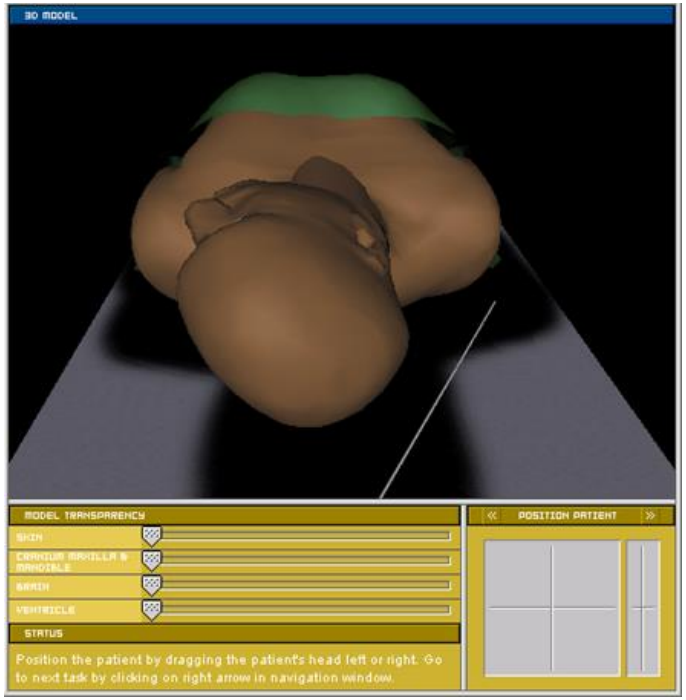
- H3D.org : X3D + Python, ECMAScript, C++
- Rigid Body Physics
- OpenGL rendering
- Chai3D haptics renderer

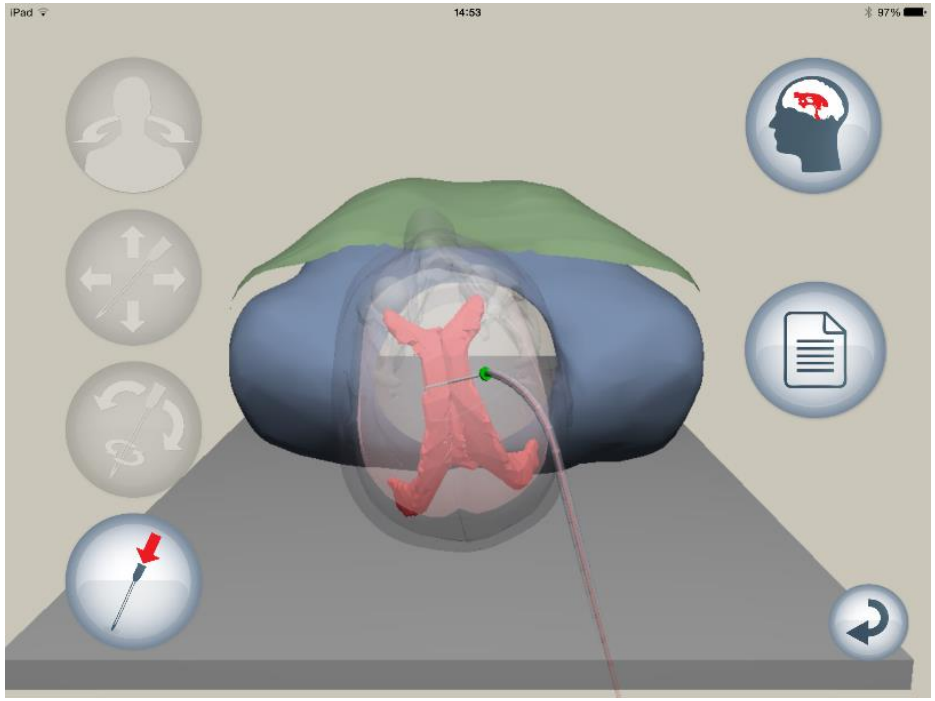


SenseGraphics

Tiered Training: Nigel John

- Ventricular Catheterization:
  across platforms workstation and mobile

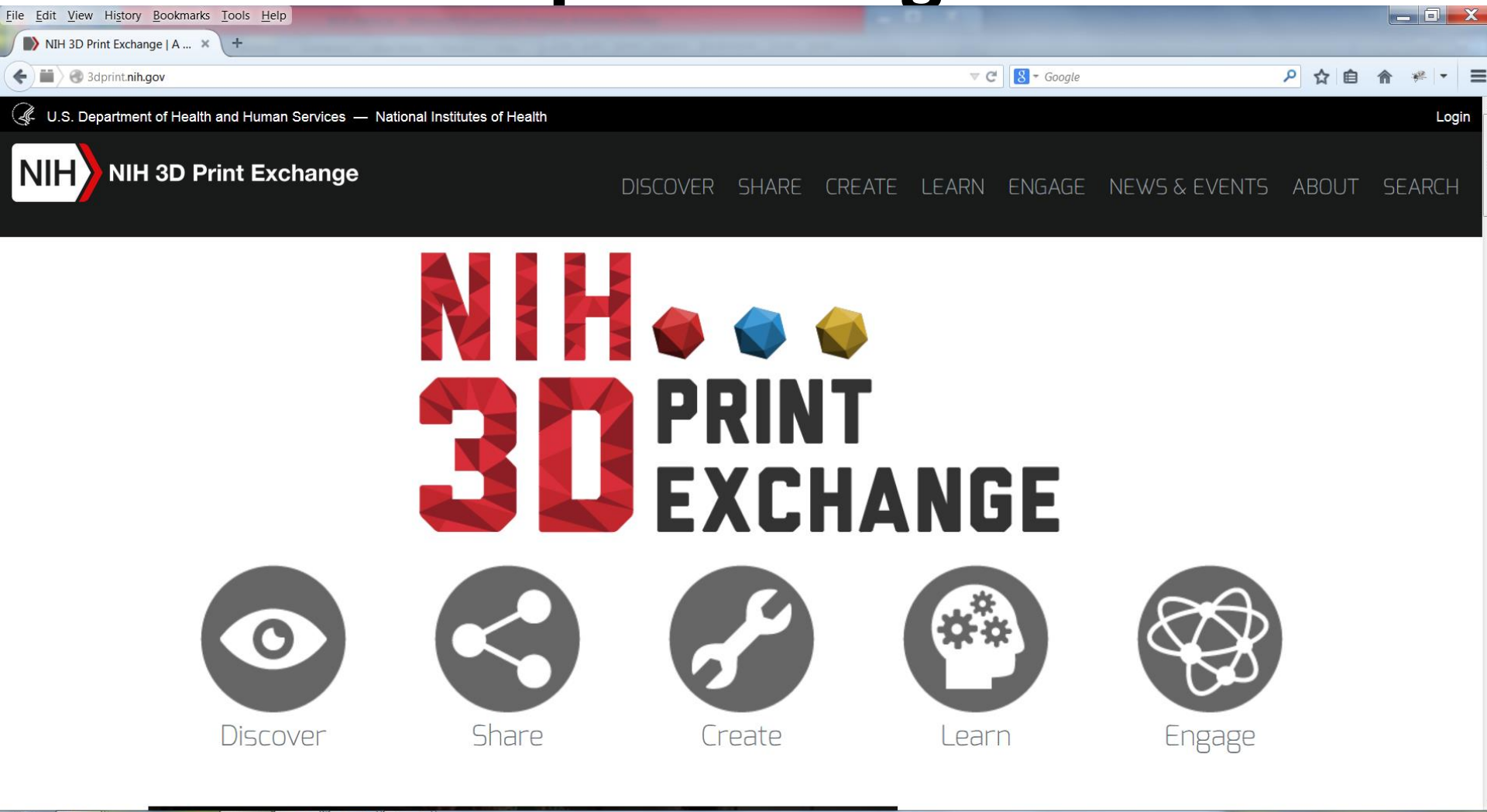




CSIRO

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

3dprint.nih.gov



e-NABLE Printed Prosthetics

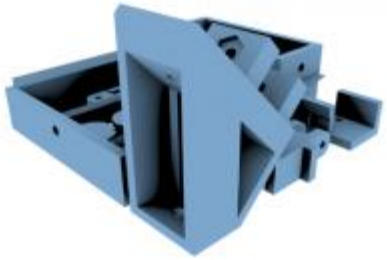
NIH 3D PRINT EXCHANGE

http://enablingthefuture.org/

3dprint.nih.gov

- Molecules
- Cells & tissues
- Anatomical models
- Prosthetics
- Labware
- …

NIH 3D PRINT EXCHANGE

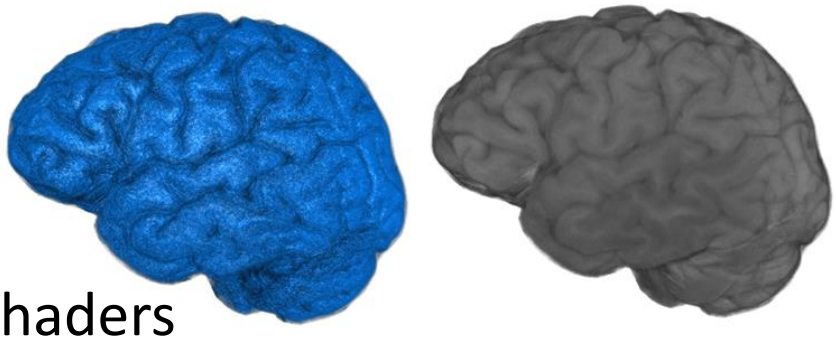


Imaging & Scanning

Tackling the challenges of:

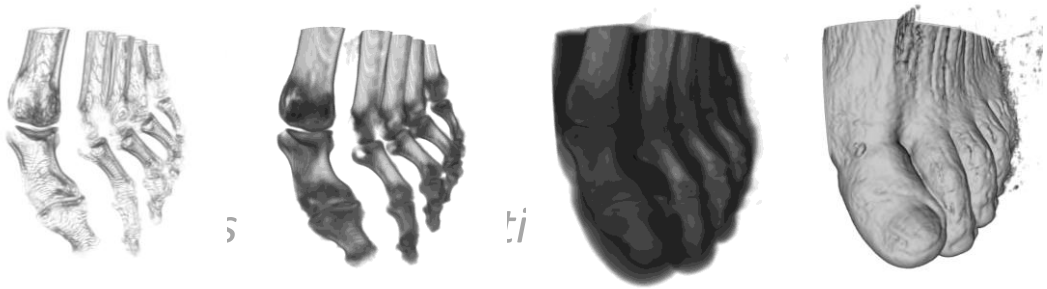
- Cross-platform volume rendering (from PACS to phone)
- Patient-specific, holistic medicine for better outcomes
- Metadata for health informatics

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



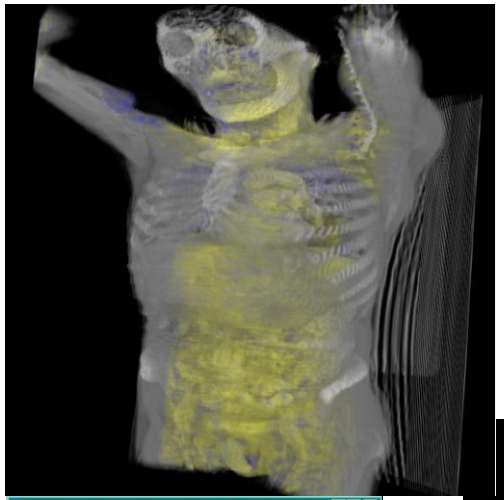
Volumes: Lots of Tools & Domains

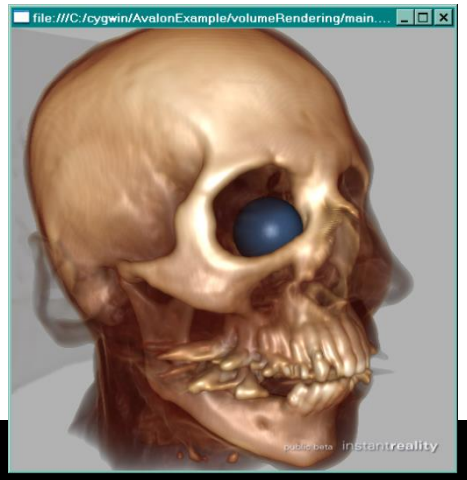
- VTK-ITK, ITK-Snap
- Seg3D
- Slicer
- 3DVisualizer
- Voreen
- Osirix

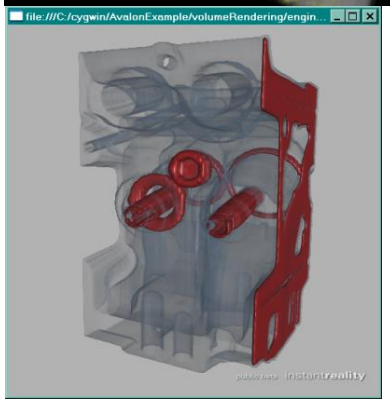
Reproducibility

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

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







ISO Standards

Cross-platform Scene Graph representations with multiple encodings and APIs:

- **Extensible 3D (X3D)**
  - Rich 3D content model including support for: DCC, CAD/BIM, Geospatial, Volume Vis, HTML5/WebGL (X3DOM)…
- **Humanoid Animation (H-Anim)**
- **Virtual Reality Modeling Language (VRML)**

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***

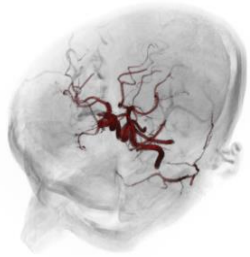
  Of 3D rendering & blending:
    - BoundaryEnhancementVolumeStyle
    - CartoonVolumeStyle
    - ComposedVolumeStyle
    - EdgeEnhancementVolumeStyle
    - OpacityMapVolumeStyle
    - ProjectionVolumeStyle
    - ShadedVolumeStyle
    - SilhouetteEnhancementVolumeStyle
    - ToneMappedVolumeStyle

Opacity Map

Silhouette

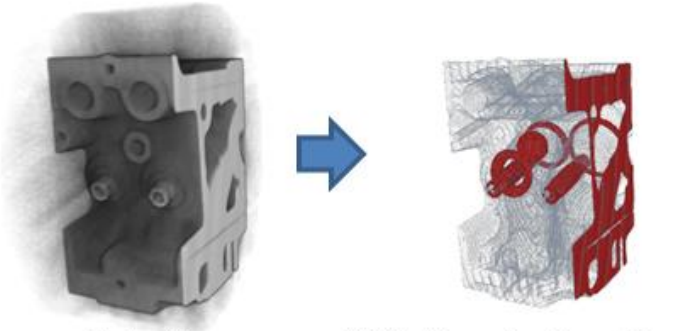
Cartoon

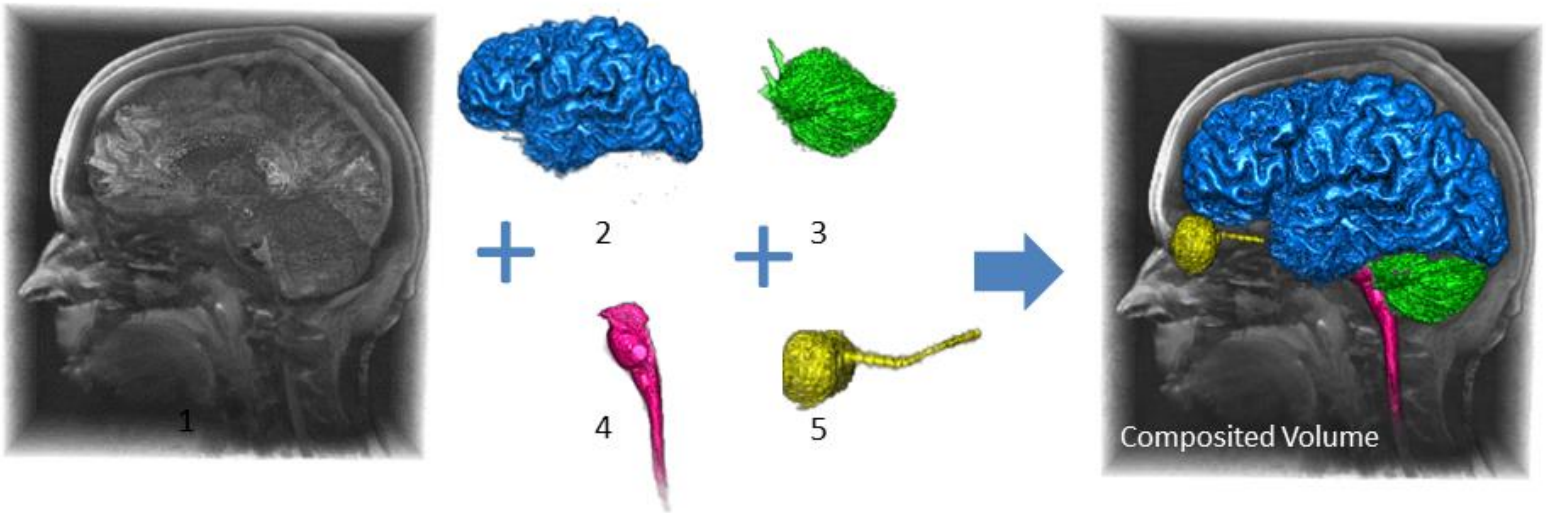
- Assign different RenderStyles to different segments, blend two volumes:
  - BlendedVolumeStyle
  - SegmentedVolumeData
  - IsoSurfaceVolumeData



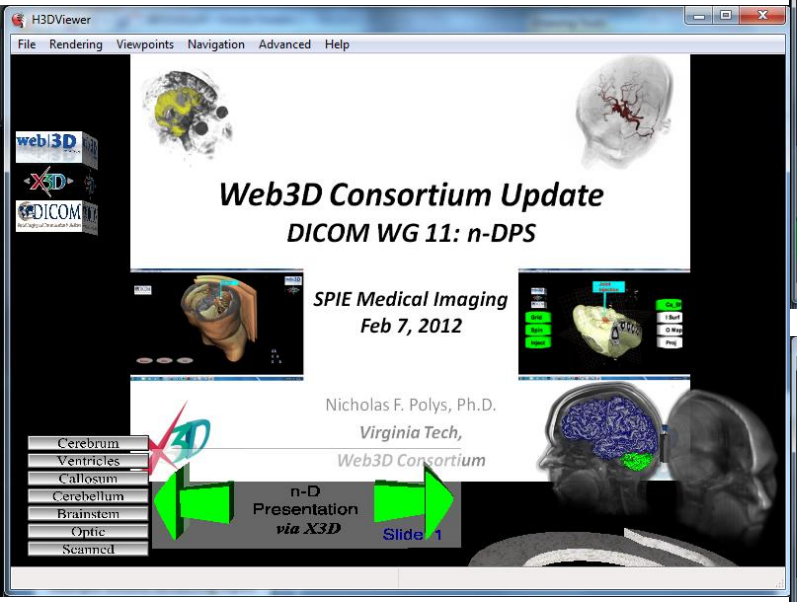
- Clipping Planes are already specified in X3D 3.2 Rendering Component!

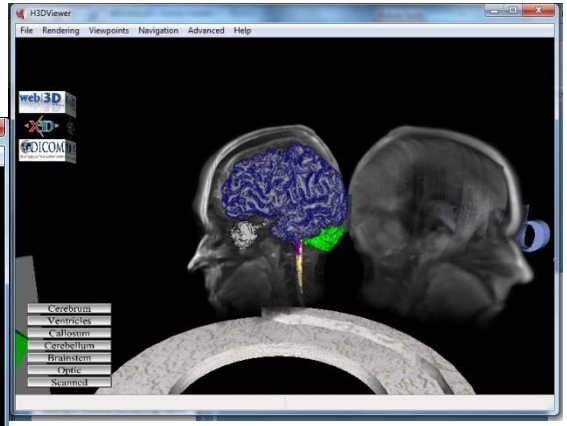
Composable X3D Volume RenderStyles

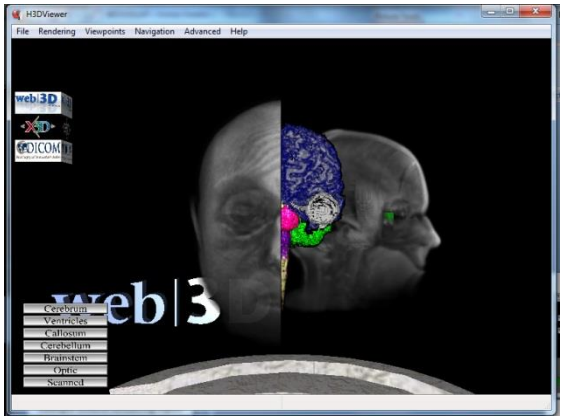


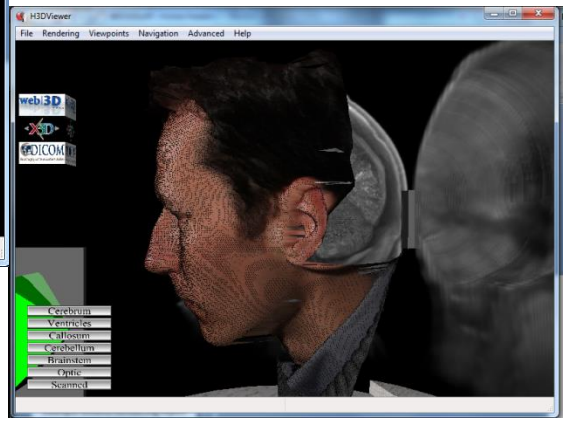


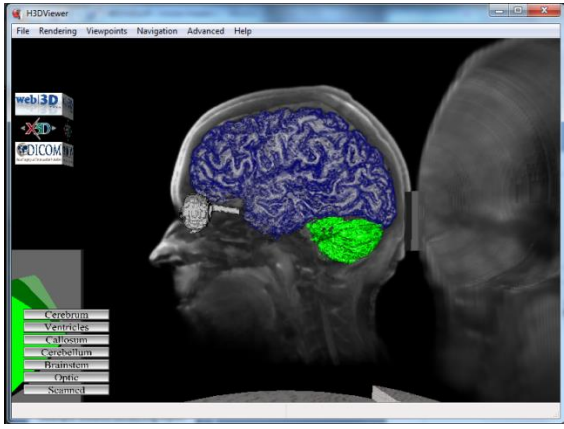
X3D Presentation Demo











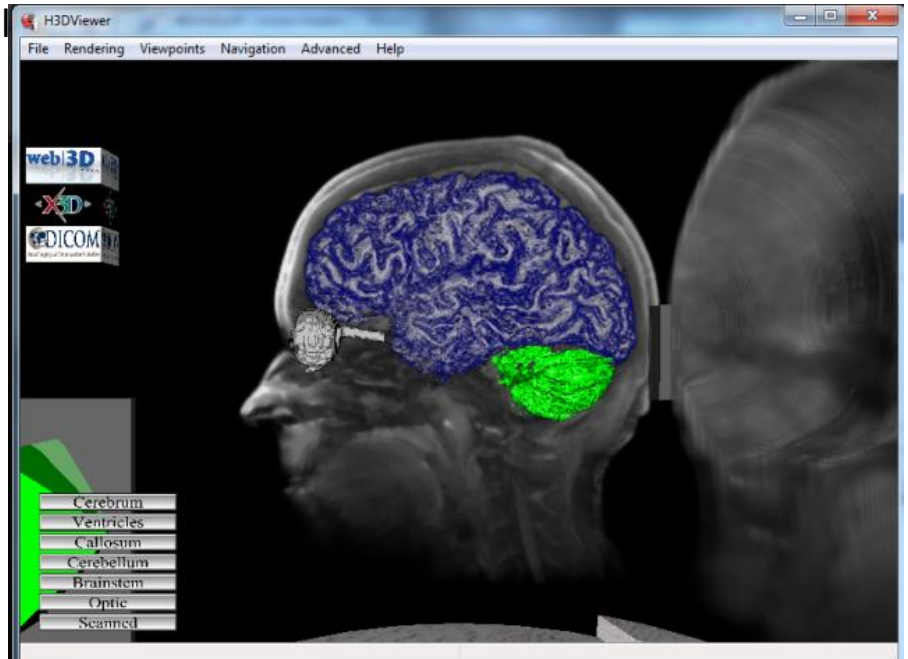
Screenshots

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="voxel
        <OpacityMapVolumeStyle />
    </VolumeData>
</Transform>
```



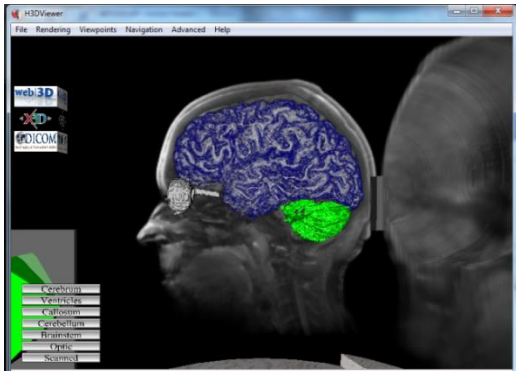
Example Volume Rendering Styles

(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>
```

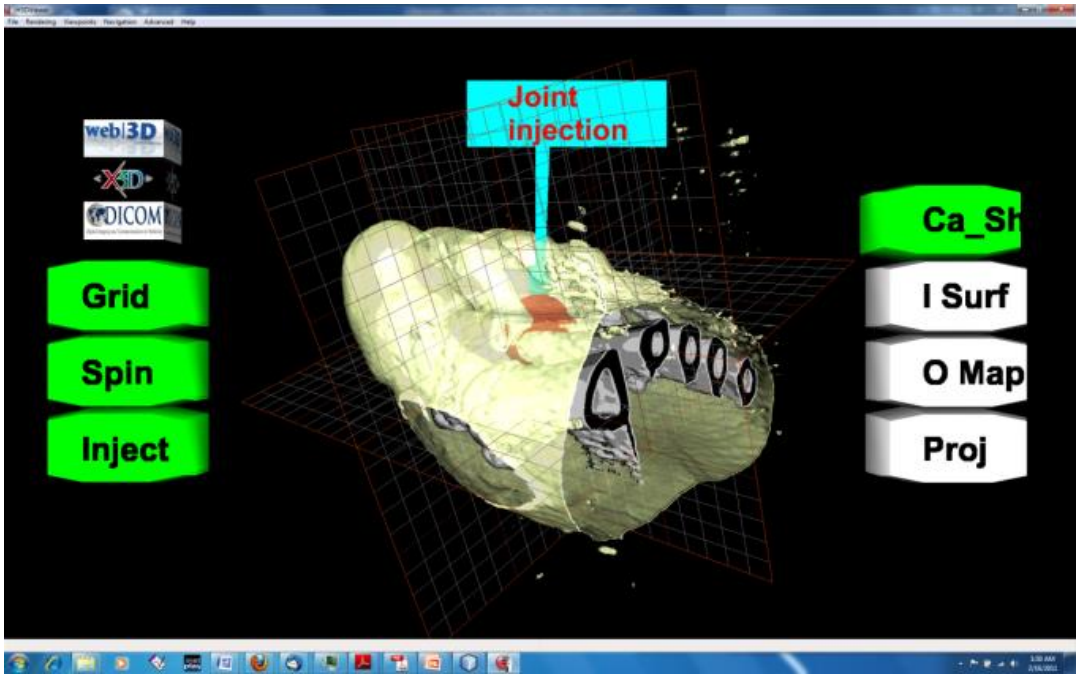


X3D Medical Interchange Profile

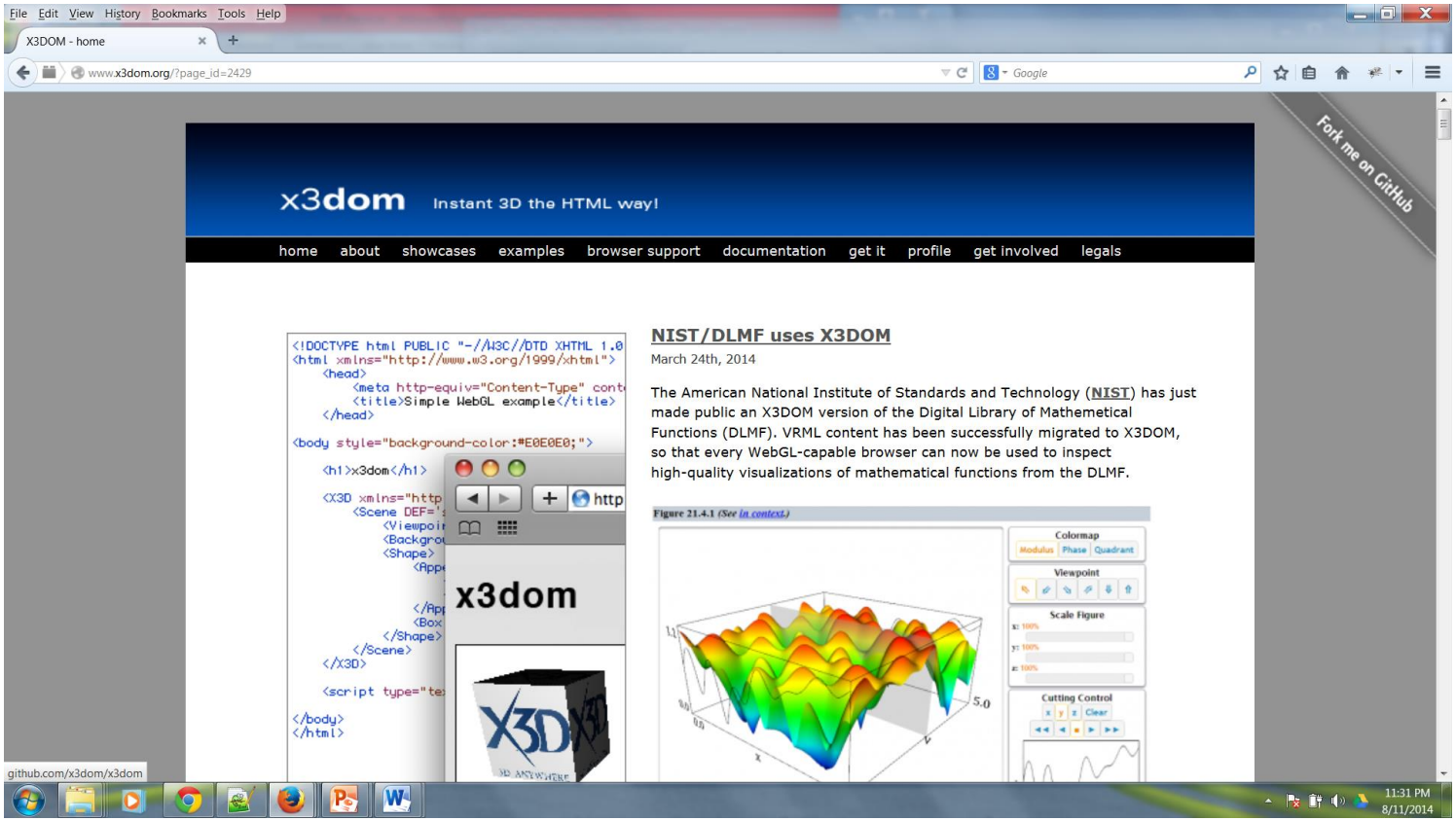
Minimal X3D node set (footprint) to meet DICOM requirements:

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



X3DOM.org =
HTML5 + WebGL + X3D



Fraunhofer IGD

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

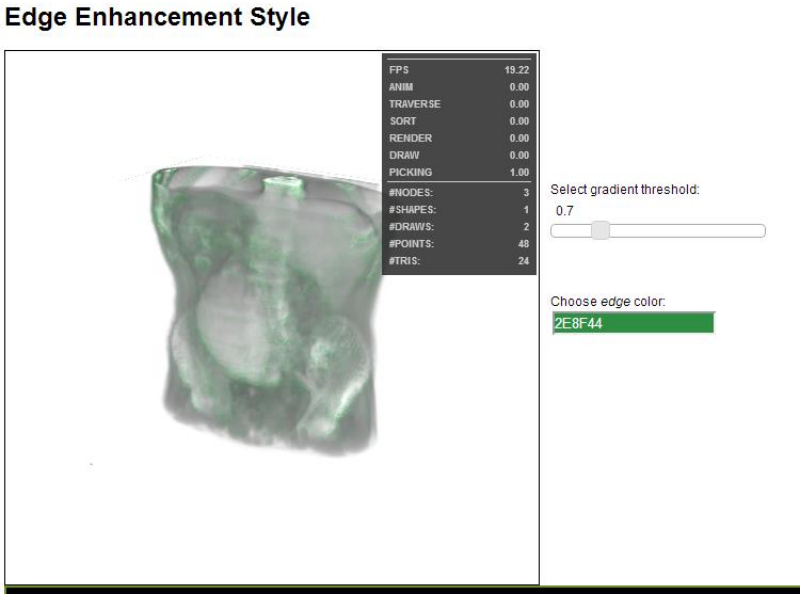
… **X3DOM.ORG …**

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

See Also: the industrial strength *InstantReality.org*

WebGL Volume Rendering

- X3D Volume RenderStyles implemented in X3DOM
- Tools for publishing
  in web browser
  (See Web3D Tutorials)
- VolumeRC.org
  examples

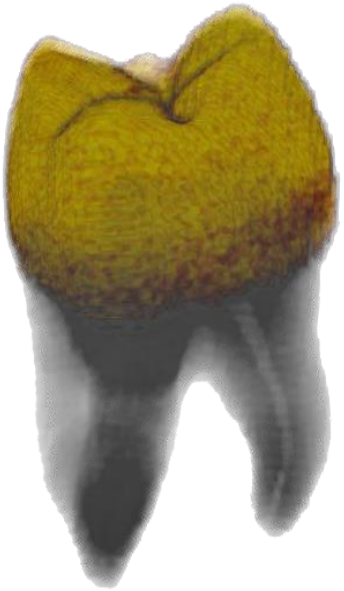


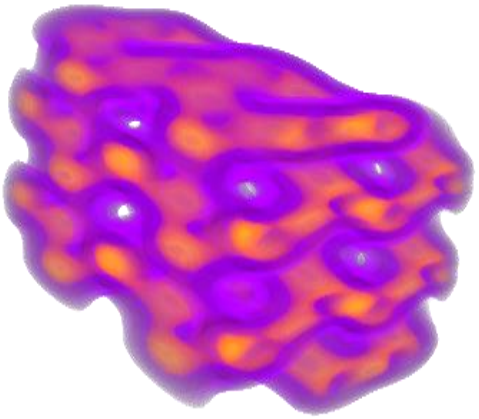
medx3dom, volume rendering with WebGL

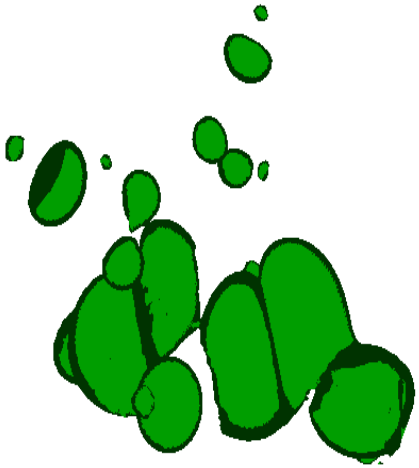
Ander Arbelaiz, Luis Kabongo,
Aitor Moreno
Vicomtech-IK4

x3dom volume rendering

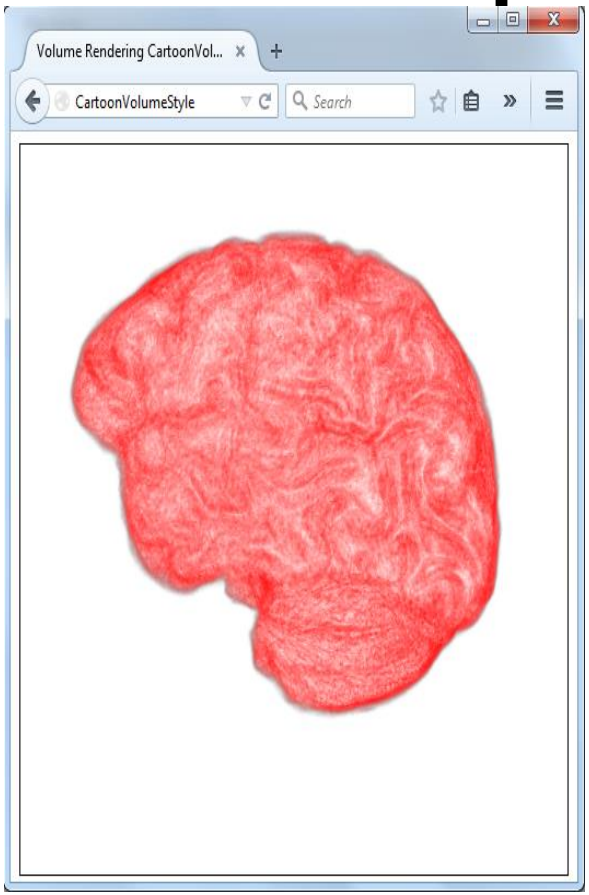
- WebGL based volume rendering
  - Active development towards X3D v3.3 compliance, added support for composable rendering styles.

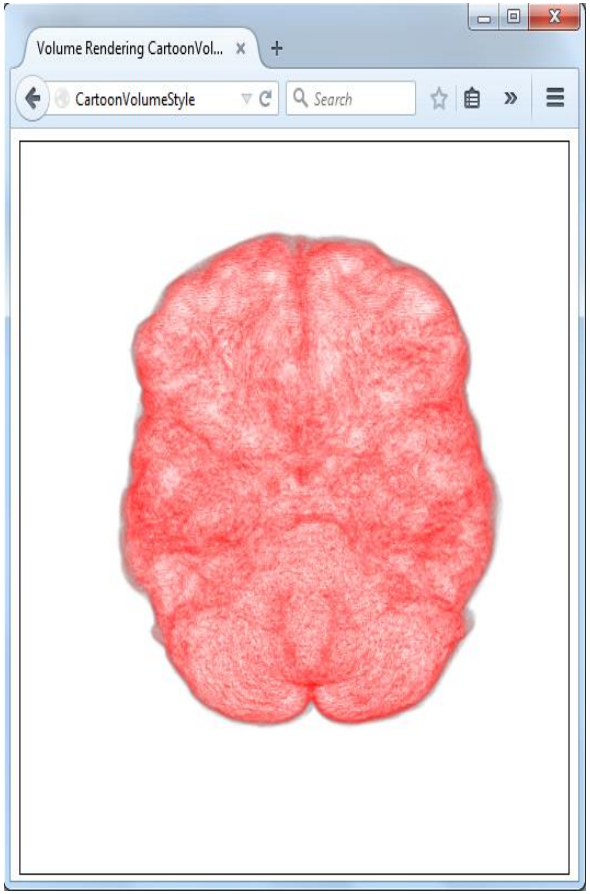




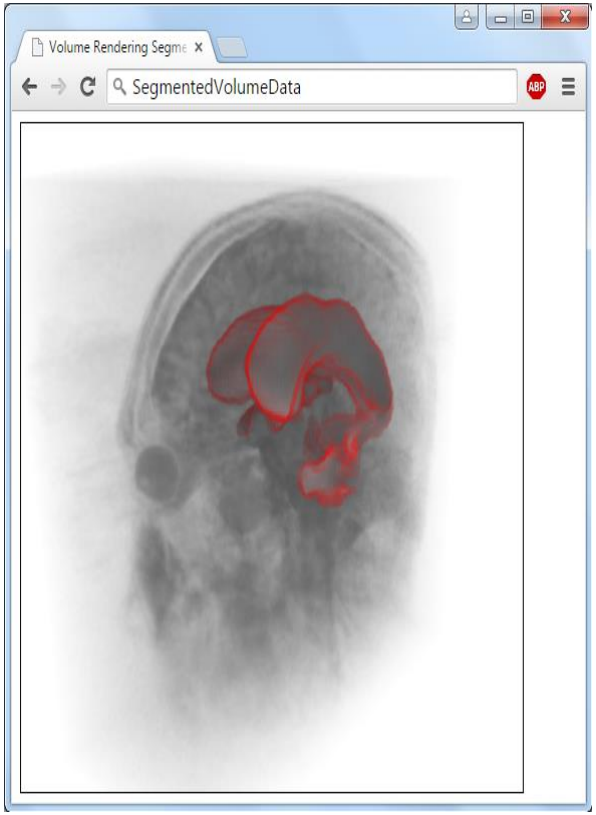


Example of CartoonVolumeStyle



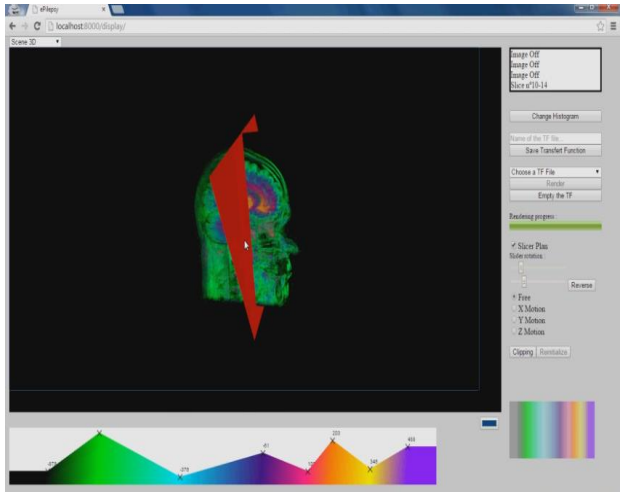


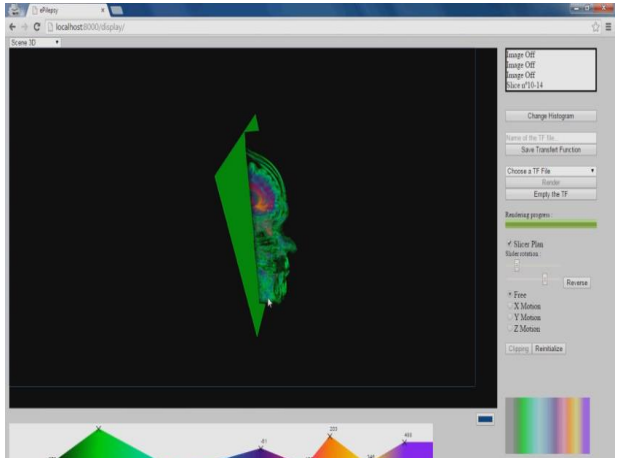
Example of SegmentedVolumeStyle



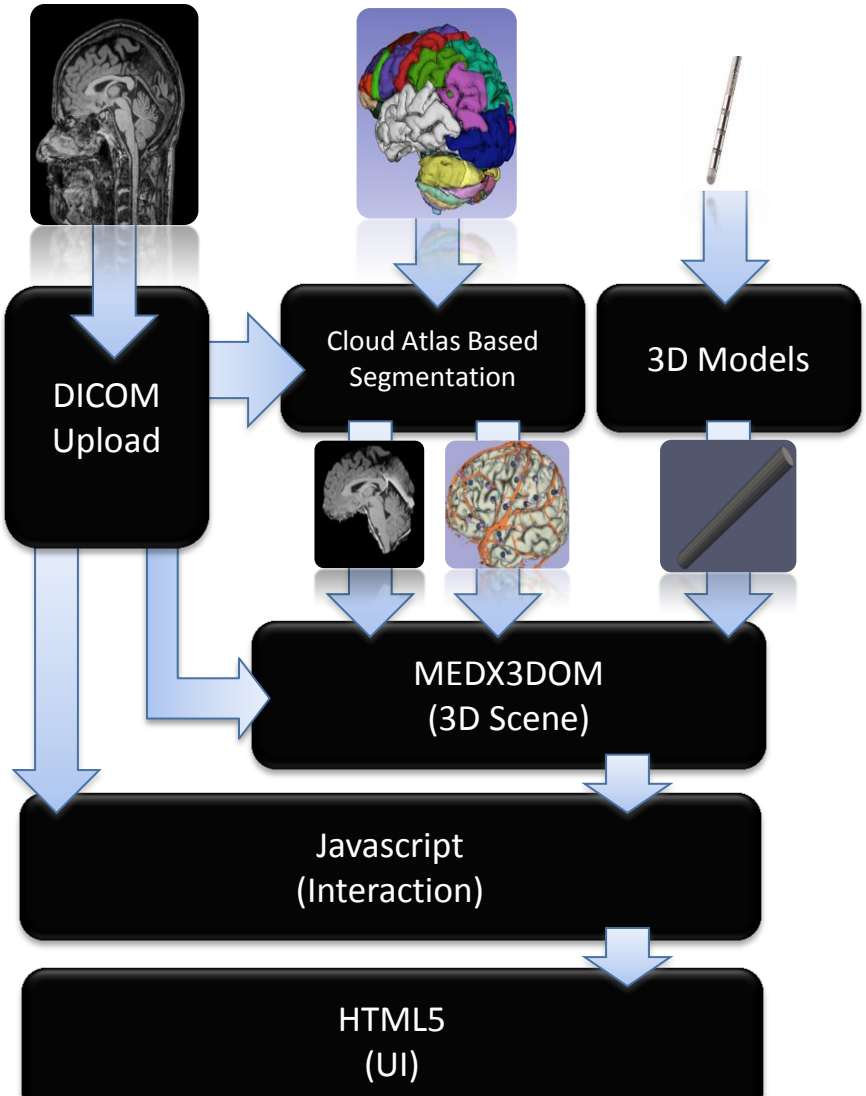
e-Pilepsy

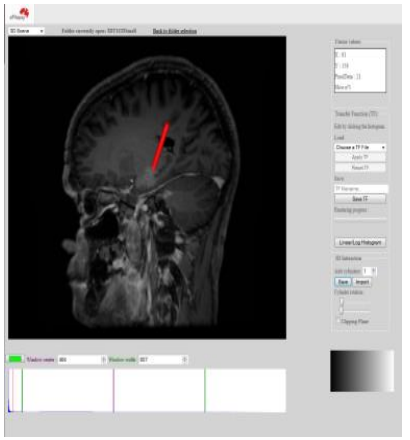
- Web based project for 3D neurosurgery training in epilepsy treatment
- Cloud based image processing
- Web visualization & interaction (X3DOM)

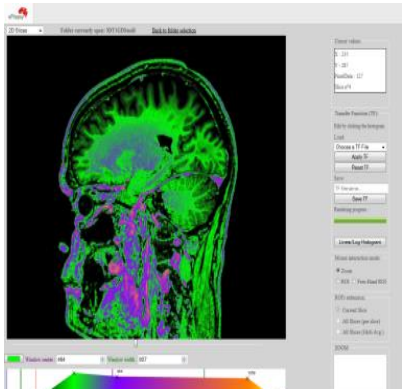




Architecture







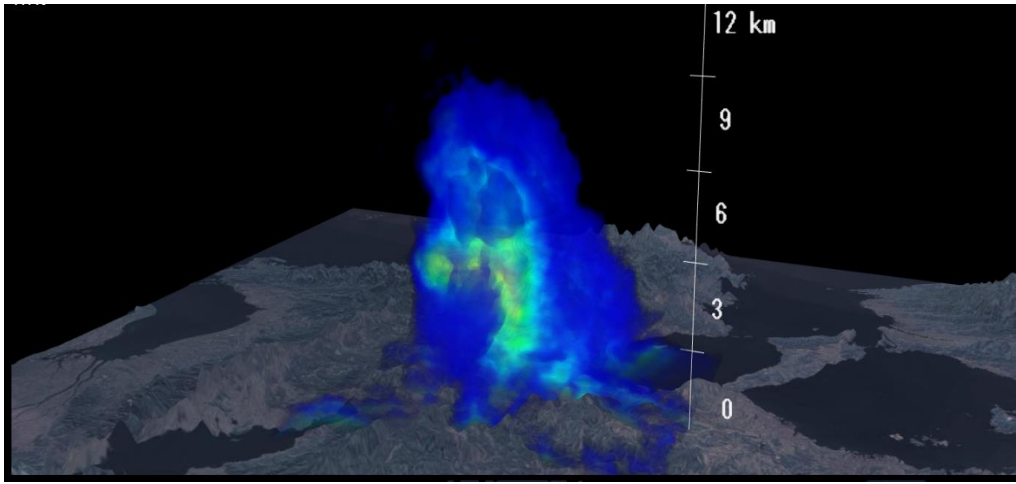
Online examples and demos

- www.x3dom.org/examples
- www.volumerc.org
- http://demos.vicomtech.org

Toshiba

- Geospatial weather radar visualization
- Early warning safety
- X3DOM Volume Rendering w texture compression scheme

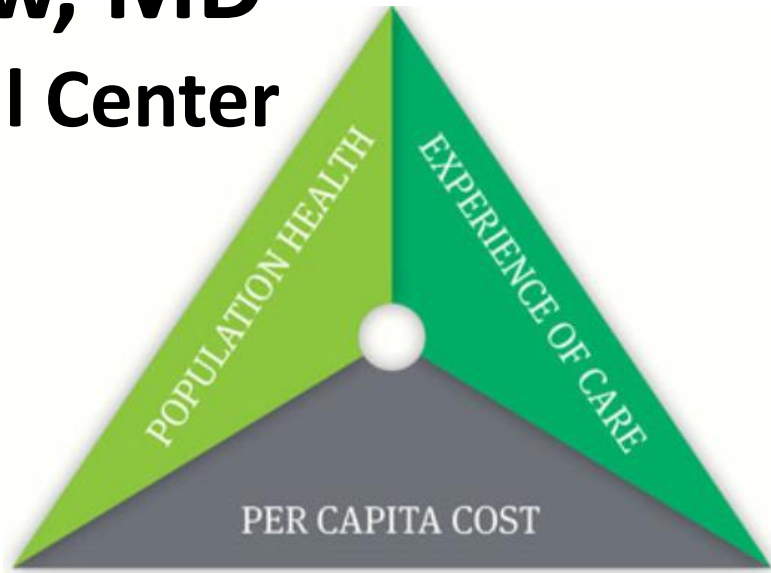
- Web3D 2015 paper!



Michael Aratow, MD

San Mateo Medical Center

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



Source: IHI Triple Aim

Health Information Exchange

Share information

Increase efficiency

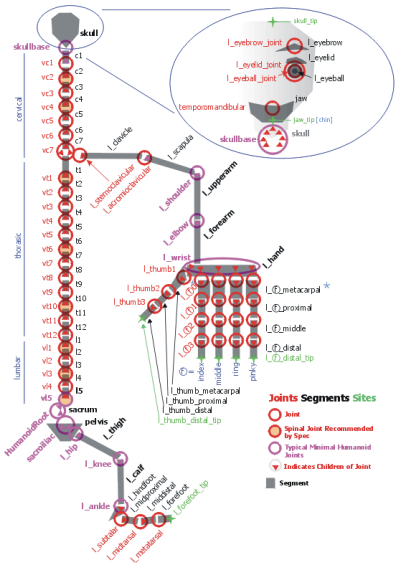
Empower patients

Increase transparency

Leverage technology for new insights

Humanoid Animation (H-Anim)

- ISO standard for virtual characters: multiple Levels-Of-Articulation (LOAs)
- Specifies skeletal hierarchy with joints, segments, and a skin
- Convergence to Medical terminology, anatomical objects and sites



Web3D.org: Get Involved !

Drive the future of Web3D technologies:

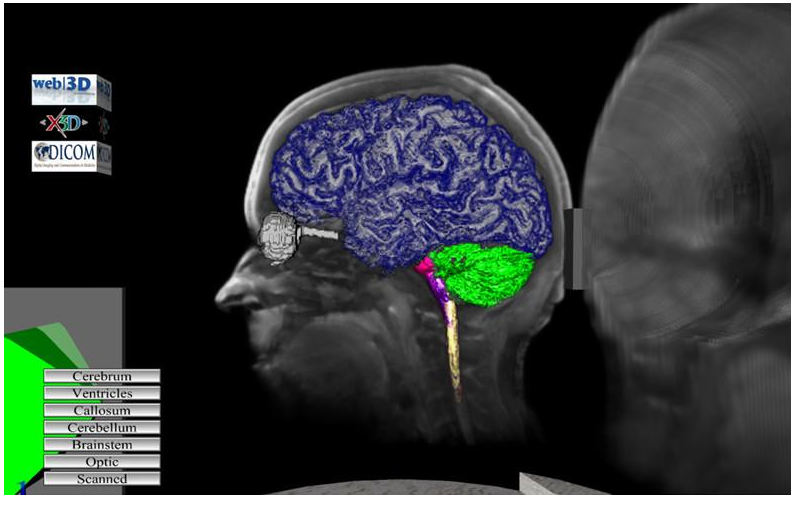
- Open Listerves and public wiki
- Weekly Working Group telecons
- Members' Area, SDO Liaisons
- Open Source codebases
- Web3D Example sets
- Current Projects include:
  - X3DOM = HTML5 + X3D + WebGL
  - Cultural and Natural Heritage
  - Blender, Unity, … importers / exporters
  - VR & AR visualization services
  - *… see more online!*

Acknowledgements

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

Learn More!

Booth 1018



Join Us!

www.Web3D.org

X3D Medical Working Group

web|3D CONSORTIUM

1872 VirginiaTech *Invent the Future*

Supplemental Material

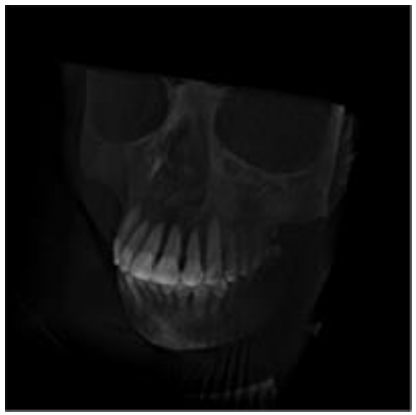
- Web3D 2013 Tutorial is online (excerpts below)
- See web3d.org Medical WG Public Wiki

http://www.web3d.org/wiki/index.php/X3D_Medical

Rendering a Volume: VolumeData Node

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

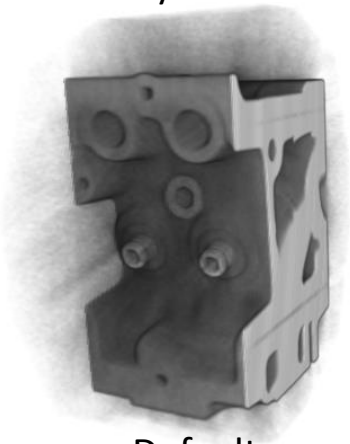
```
<VolumeData dimensions='1.28 1.28 1.0' >
        <!-- VolumeRenderStyle node here (optional) -->
        <ImageTexture3D containerField='voxels' url='  "path_to_dataset" '/>
</VolumeData>
```



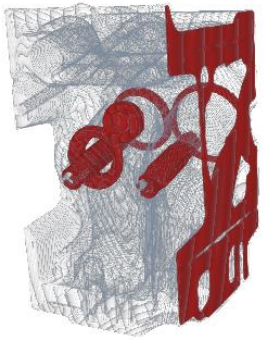
Opacity Map VolumeStyle

- 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

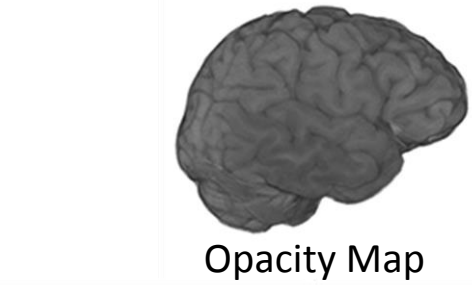
Projection VolumeStyle

- 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'/>
```

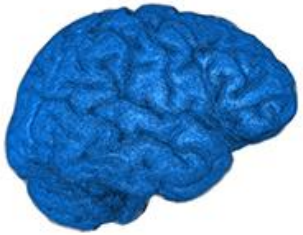
Per-Voxel VolumeStyles

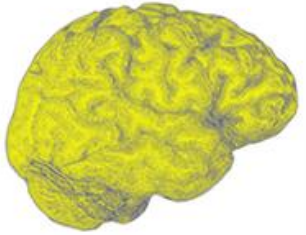
- View-Dependent
  - Opacity Map (default)
  - Enhancement Styles
    - Boundary, Edge, Silhouette
  - Cartoon
- Lighting-Dependent
  - Tone Map
  - Shaded


Opacity Map

Edge Enhanced

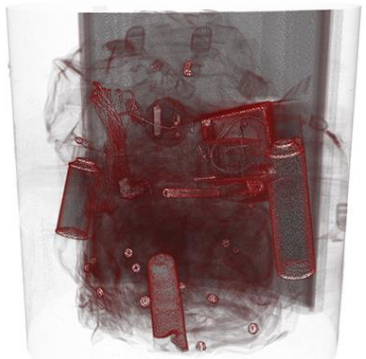
Cartoon


Shaded

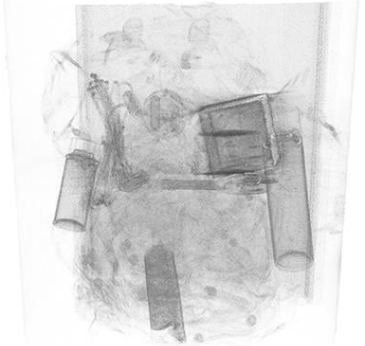

Tone Map

Combining Styles: ComposedVolumeStyle

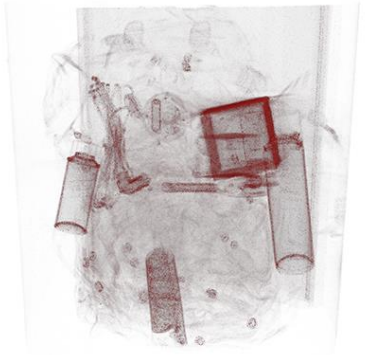
```
<ComposedVolumeStyle enabled='true' ordered='false' containerField='renderStyle'>
        <SilhouetteEnhancementVolumeStyle silhouetteBoundaryOpacity='1'
          silhouetteRetainedOpacity='.1' silhouetteSharpness='10' enabled='true'
          containerField='renderStyle'/>
        <EdgeEnhancementVolumeStyle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



Style1 (Edge Enhance)



Style2 (Silhouette)



Composed Styles

Rendering a Volume: IsoSurfaceVolumeData

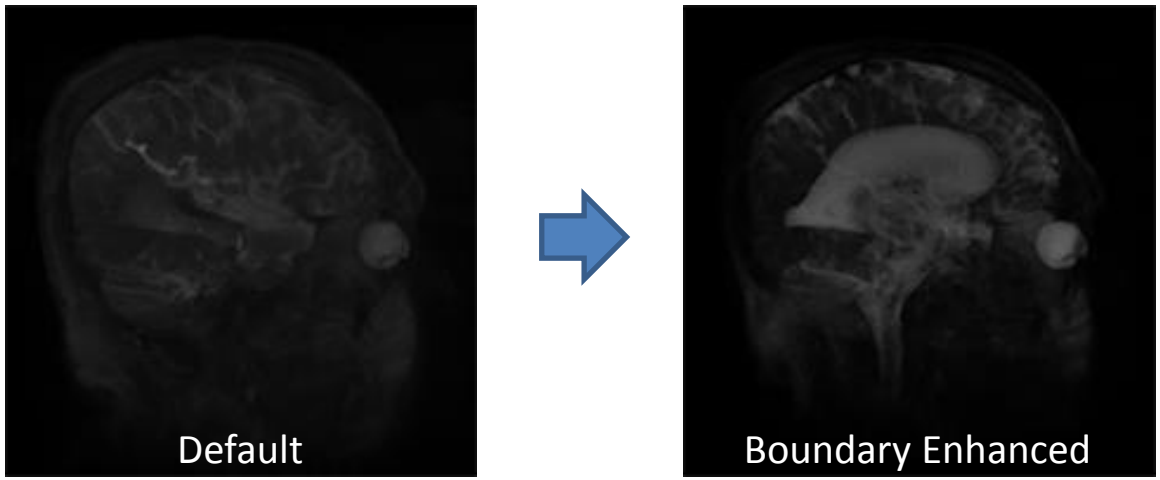
- Similar to the basic VolumeData node, but renders a surface across voxel gradients

```
<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:

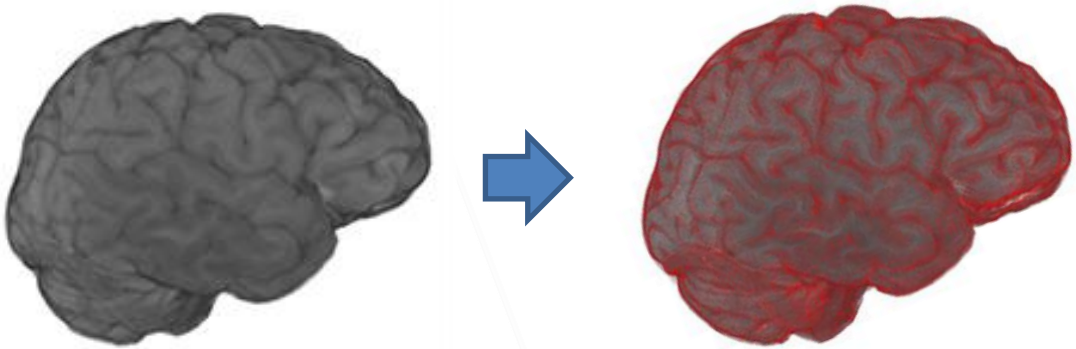
```
<BoundaryEnhancementVolumeStyle boundaryOpacity='0.9' opacityFactor='0.9'
  retainedOpacity='0.2'>
```



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'/>
```



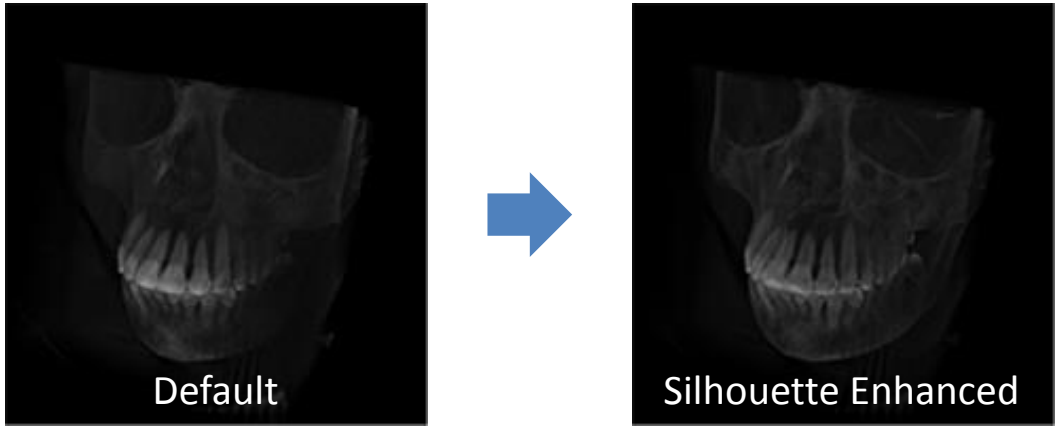
Default

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

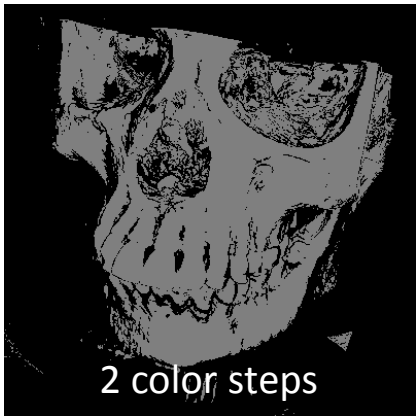
```
<SilhouetteEnhancementVolumeStyle silhouetteBoundaryOpacity='1'
  silhouetteRetainedOpacity='.5' silhouetteSharpness='10' enabled='true'
  containerField='renderStyle'/>
```

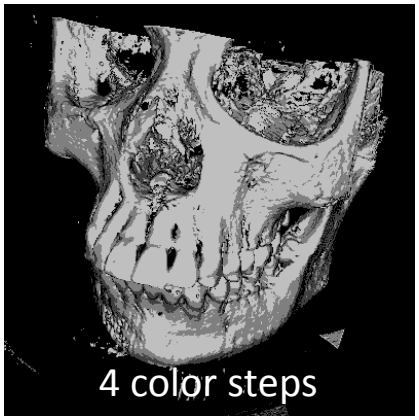


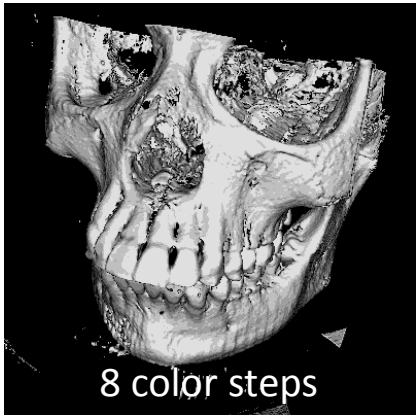
Cartoon VolumeStyle

- 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'/>
```



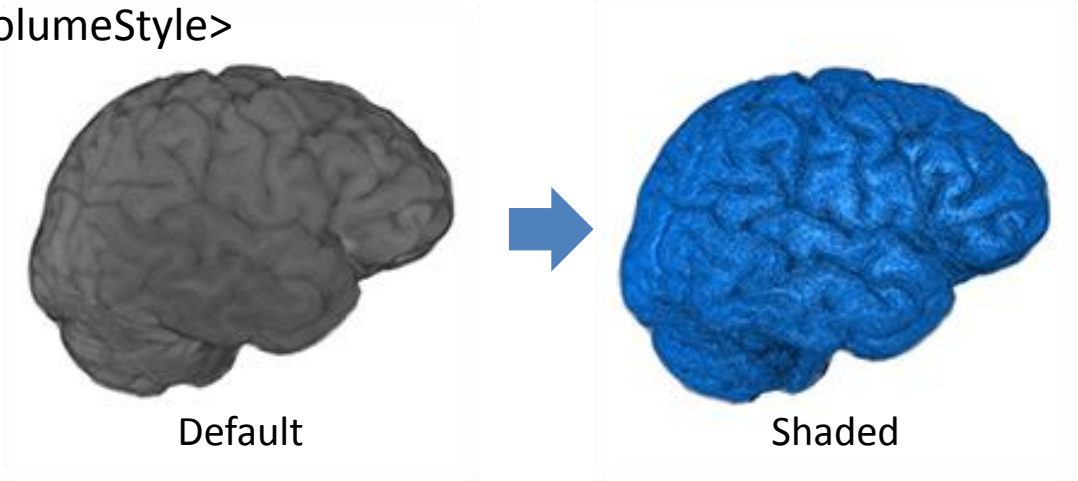




Shaded VolumeStyle

- 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>
```



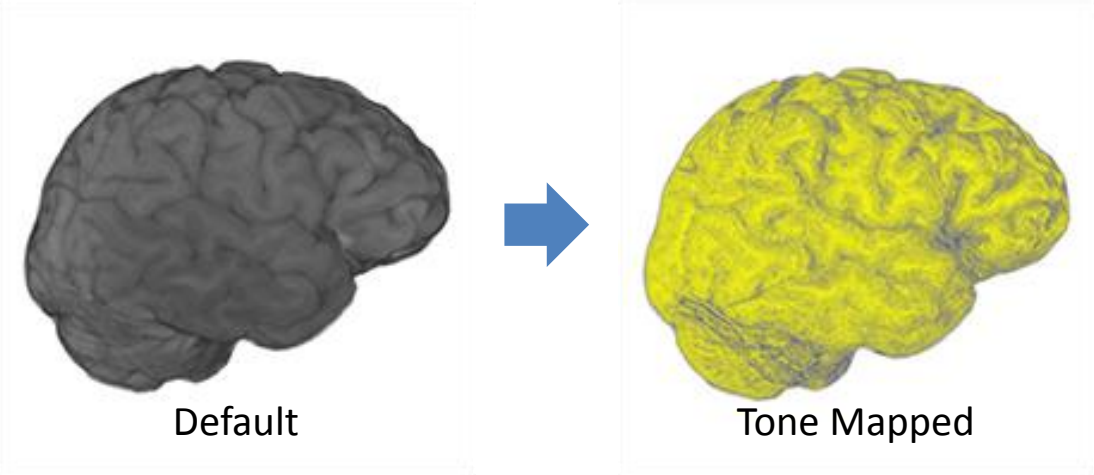
Default

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' />

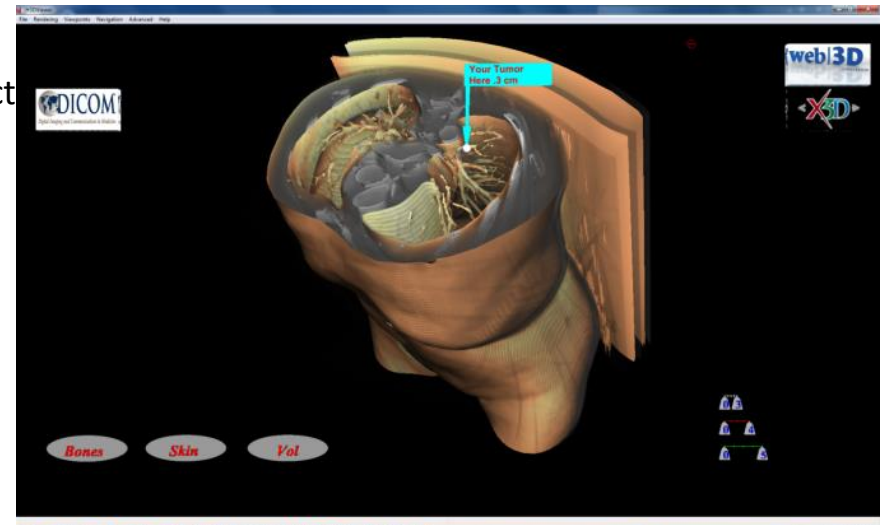


Default

Tone Mapped

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 xxxxx.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 inspect
  - Seg3D.org
  - Slicer.org; ITK-Snap
  - X3D-Edit 3.3
- **Viewers**
  - H3D.org
  - InstantReality.org