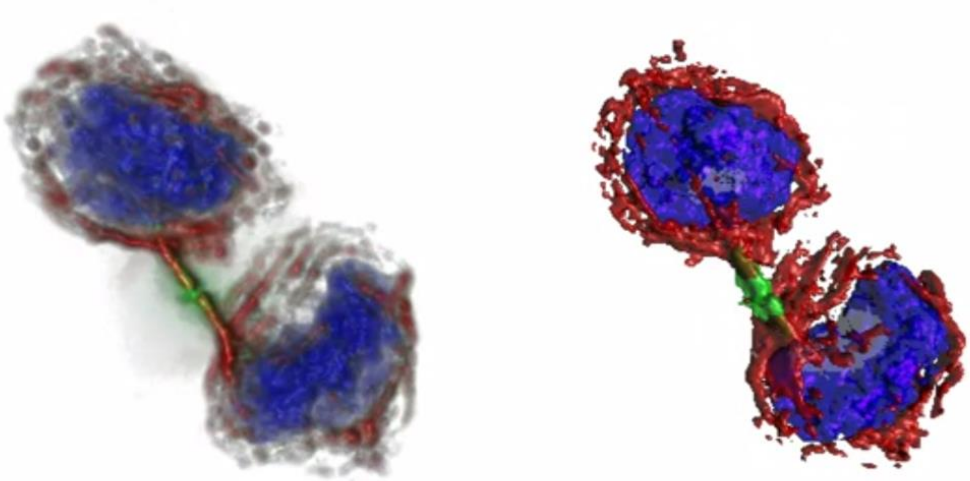
Volume Rendering and Medical Visualization Using X3D

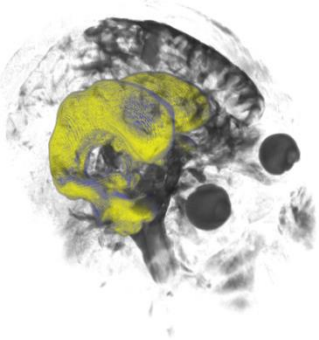
SIGGRAPH 2013 BOF



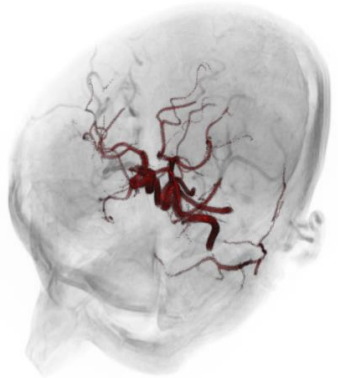
Nicholas Polys, Ph.D. ; Andrew Wood, Abhijit Gurjarpadhye
Web3D Consortium, Virginia Tech

Mike Aratow, MD, FACEP
Web3D Consortium

Peter Leskovsky, Ph.D.; Luis Kabongo, Ph.D.
Web3D Consortium, VicomTech



Agenda

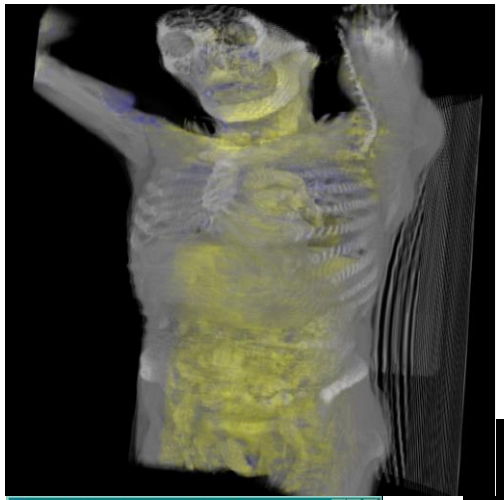


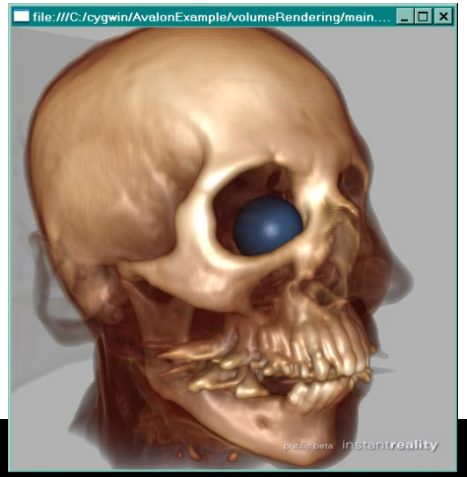
- The Web3D Community & the Web3D Consortium
- Working Group progress
  - Specification of X3D 3.3 Volume rendering Component
  - DICOM WG 11 progress
  - Presentation & Publishing Pipelines
  - Examples
- Next steps

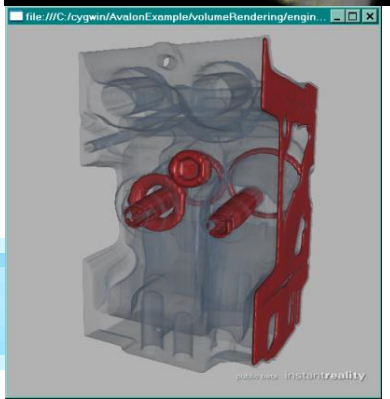
Reproducibility

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

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



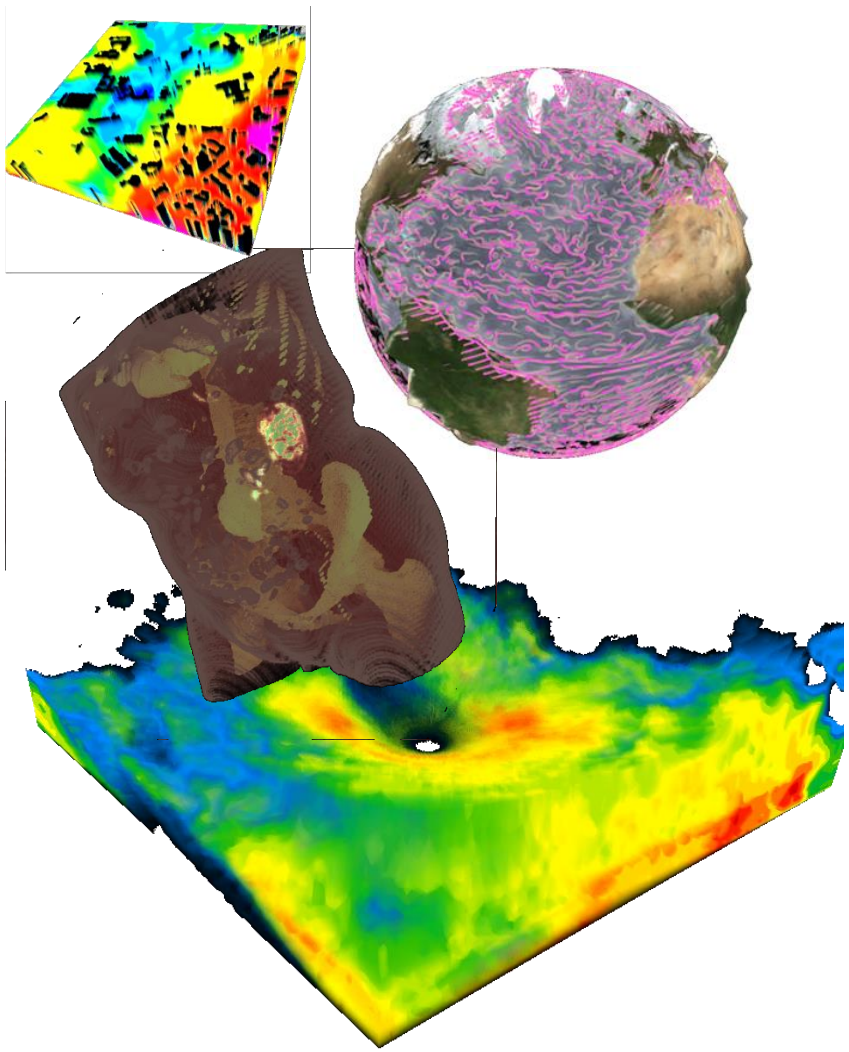




Volume Rendering: more than medical imaging

- Geology
- Meteorology
- FlowVisualization
- Microscopy
- Paleontology
- Non-invasive sensing:
  - Transportation security
  - Manufacturing QA

….



Open Standards for Interactive 3D on the Web

www.web3d.org

- Portability
- Durability
- Interoperability
- Royalty-free
- International recognition and support

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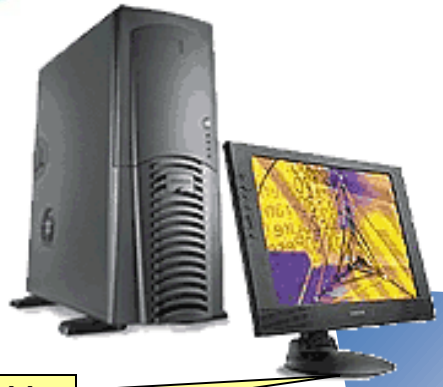
The ISO Standards for interactive 3D on the Web



Shared world wide

Shared between applications

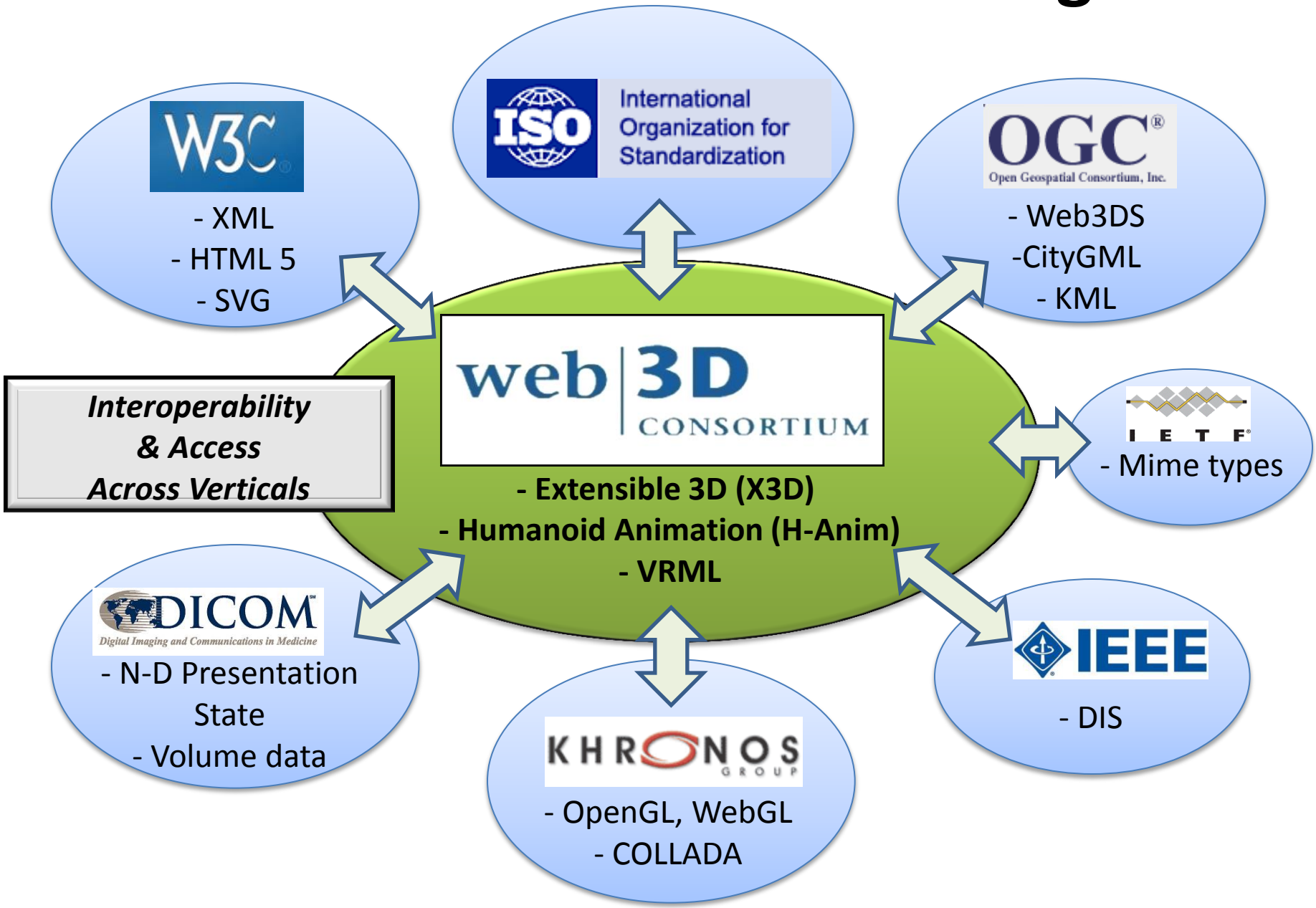
Royalty-free; Numerous implementations including Open source

"X3D enables the communication of real-time 3D across networks and XML-based web services"

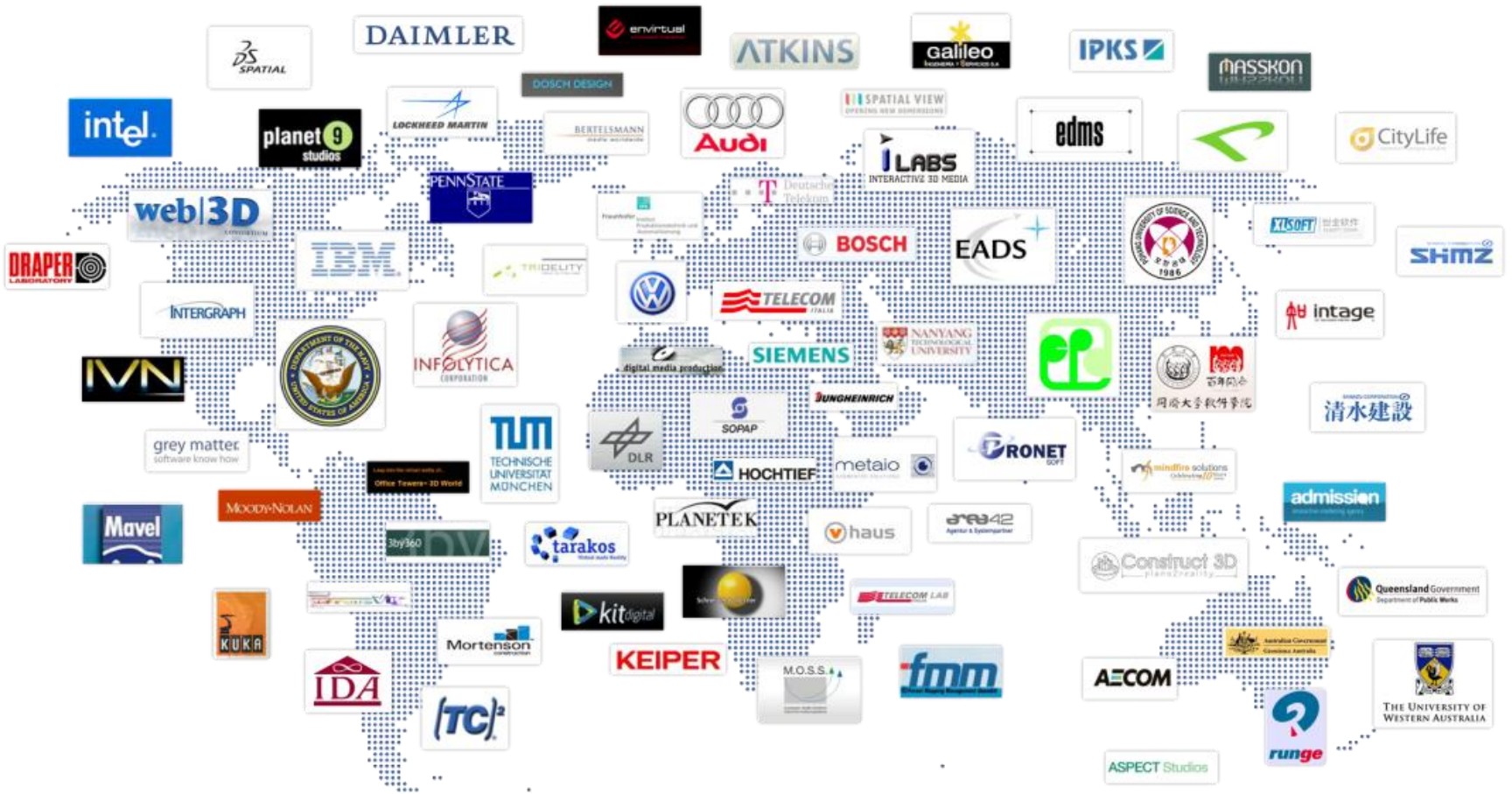
Lasts the Test of Time

Shared between systems

Web3D Collaboration & Convergence

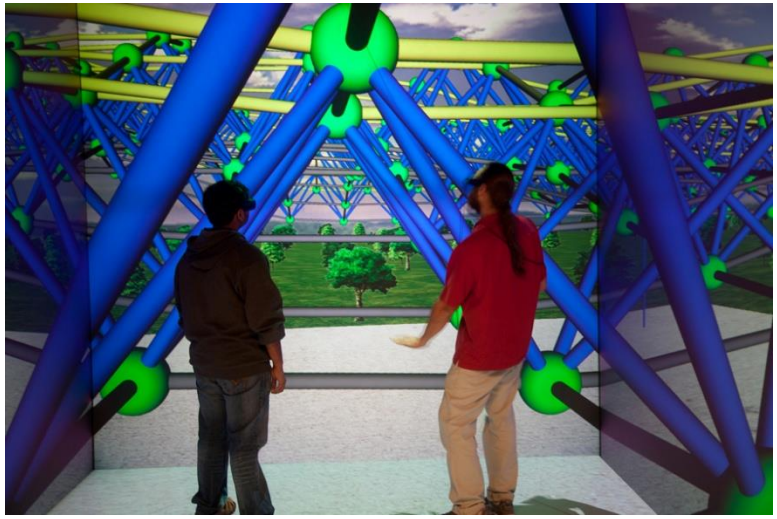


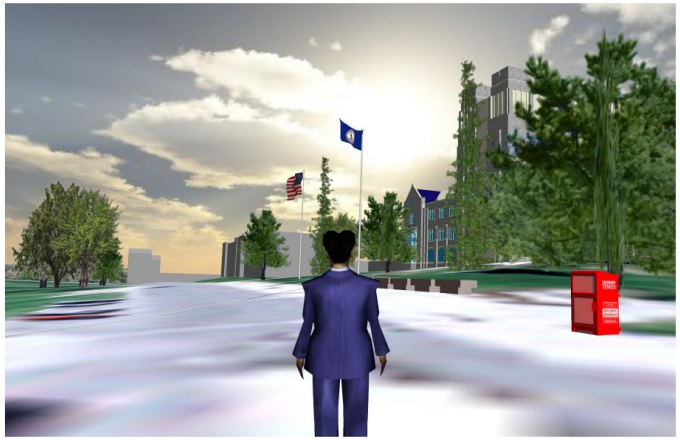
Adoption

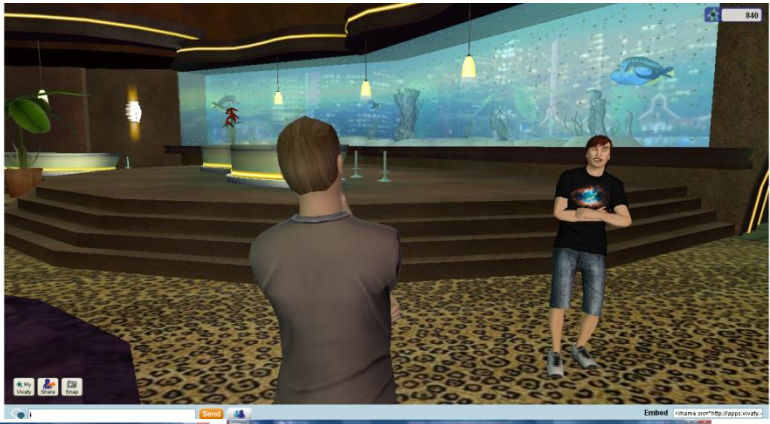


Too many to list them all!

Extensible 3D (X3D) , VRML, H-Anim

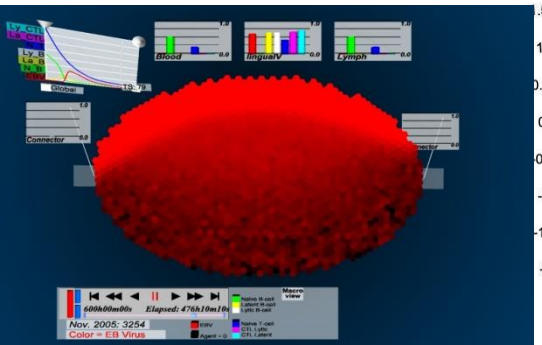


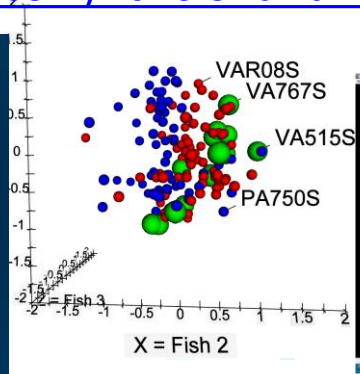


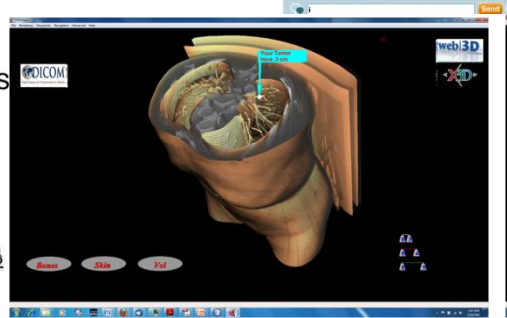


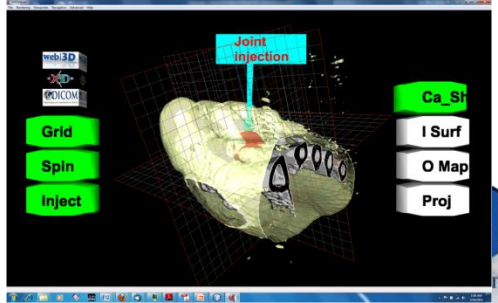
See videos and case studies at web3d.org:

- http://www.web3d.org/realtime-3d/case-studies
- http://www.web3d.org/realtime-3d/videos
- http://www.youtube.com/vtvisionarium









Web3D Community

This means You!

- We all want our assets to be portable and durable
- We all have a stake in a royalty-free future for 3D on the web
- Active Working Groups organized around vertical applications of the X3D spec: *CAD, Geospatial, Medical, Augmented Reality*
- **Join us – we are member-supported organization!**

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Events @ SIGGRAPH

- Web3D Booth # 233
- Tuesday
  - BOFs in 201D: CAD, Carto, Medical, TownHall Mtng
- Wednesday
  - BOFs in 201C: X3D Futures w/ HTML5, AR/MR
  - TechTalk (Exhibit Hall 3:45pm)

- ACM 19th Annual Web3D Conference to be Co-located with SIGGRAPH 2014, Vancouver

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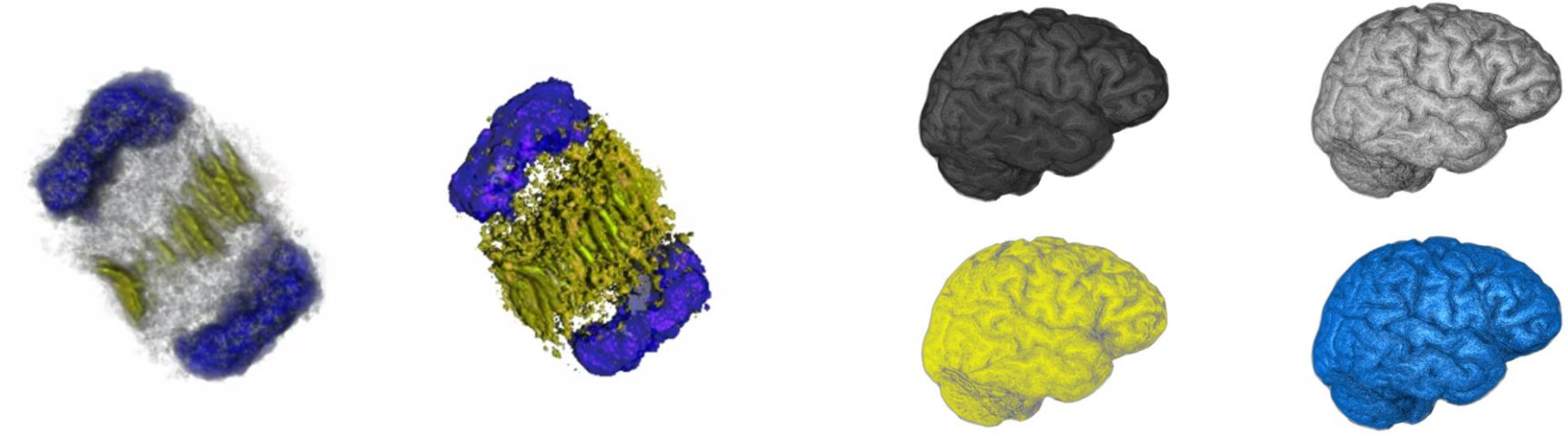
ISO Progress

- ISO FDIS: http://www.web3d.org/files/specifications/19775-1/V3.3/index.html
- Associated encodings (XML, VRML, Binary) being updated now

Examples



Web3D Medical Working Group

- Reproducible rendering for stakeholders throughout the healthcare enterprise
- An n-D Presentation must include:
  - Structured and interactive virtual environment display (2D & 3D objects and time series)
  - Platform-independent, royalty-free technology to enable vendor innovation
  - Can be rendered with or without stereoscopy
  - Openly-published

X3D Volume Rendering

- ***Necessary and Sufficient node set*** for industry's Greatest Common Denominator:
  - **Volume Component**: render styles
  - **X3D version 3.3**
- Two independent implementations:
  - www.h3d.org
  - www.instantreality.org

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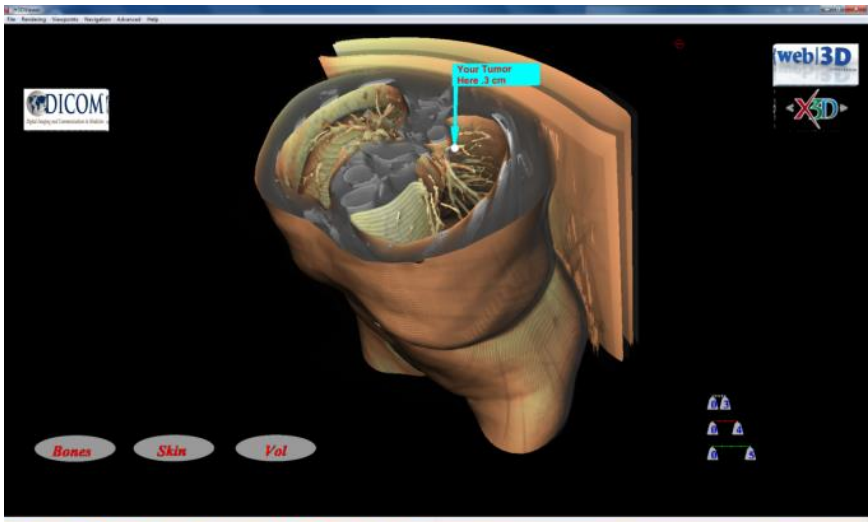
Volume Processing and Presentation Tools

- **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 inspector
  - Seg3D.org
  - Slicer.org; ITK-Snap
  - X3D-Edit 3.3
- **Viewers**
  - H3D.org
  - InstantReality.org
  - MedX3DOM



X3D Volume Rendering

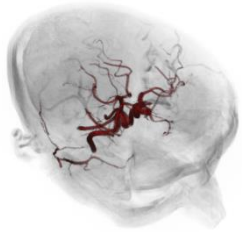
- Composable Render Styles covering the state of the art
  - Formalizes parameters and transfer functions for 3D rendering & blending
    - BoundaryEnhancementVolumeStyle
    - CartoonVolumeStyle
    - ComposedVolumeStyle
    - EdgeEnhancementVolumeStyle
    - OpacityMapVolumeStyle
    - ProjectionVolumeStyle
    - ShadedVolumeStyle
    - SilhouetteEnhancementVolumeStyle
    - ToneMappedVolumeStyle
  - ***Greatest Common Denominator***


Opacity Map


Silhouette


Cartoon

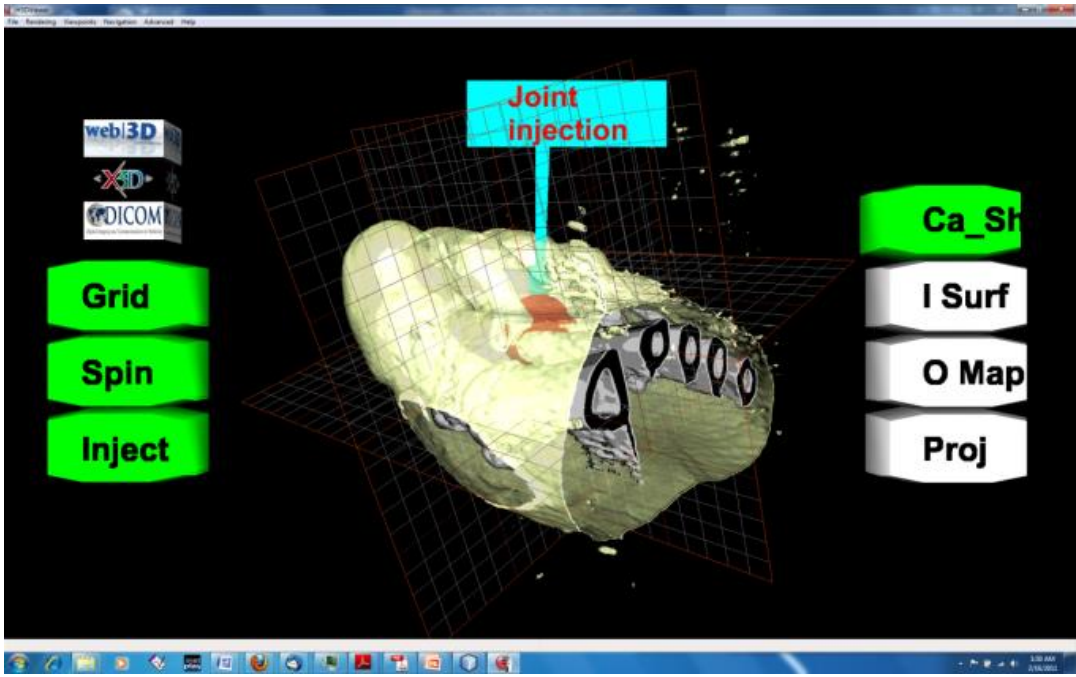
- Assign different RenderStyles to different segments, blend two volumes
  - BlendedVolumeStyle
  - SegmentedVolumeData
  - IsoSurfaceVolumeData



- Clipping Planes are already specified in X3D 3.2 Rendering Component

Medical Interchange Profile

- **X3D 3.3**
- Minimal X3D node set (footprint) to meet DICOM requirements:
  - **Core**
  - **Time**
  - **Networking**
  - **Grouping**
  - **Rendering**
  - **Shape**
  - **Geometry3D**
  - **Geometry2D**
  - **Text**
  - **Lighting**
  - **Texturing**
  - **Interpolation**
  - **Navigation**
  - **Environmental effects**
  - **Event utilities**
  - **Texturing3D**
  - **Volume rendering**



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

ISO Process

- **[X3D 3.3]** ISO/IEC FDIS 1 19775-1
  - –Clause 33 : Texturing3D Component
  - –Clause 41 : Volume Rendering Component
  - –Annex L: Medical Interchange Profile
- Final Draft International Standard (FDIS)
- Change document and unified spec drafts available to Web3D & DICOM members
  (* now published)

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/

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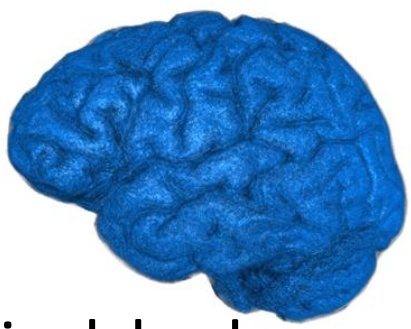
Volume Presentation

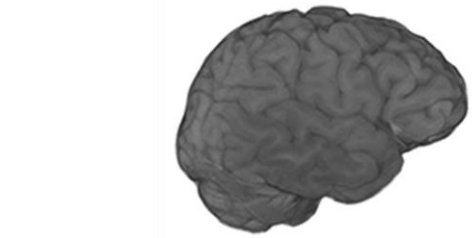


Many techniques:

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

Per-Voxel VolumeStyles

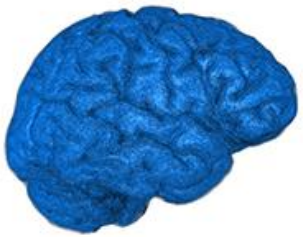
- View-Dependent
  - Opacity Map (default)
  - Enhancement Styles
    - Boundary, Edge, Silhouette
  - Cartoon
- Lighting-Dependent
  - Tone Map
  - Shaded



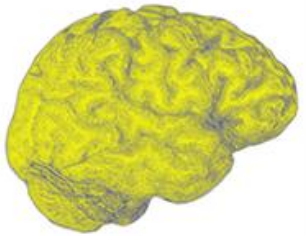
Opacity Map

Edge Enhanced

Cartoon



Shaded



Tone Map

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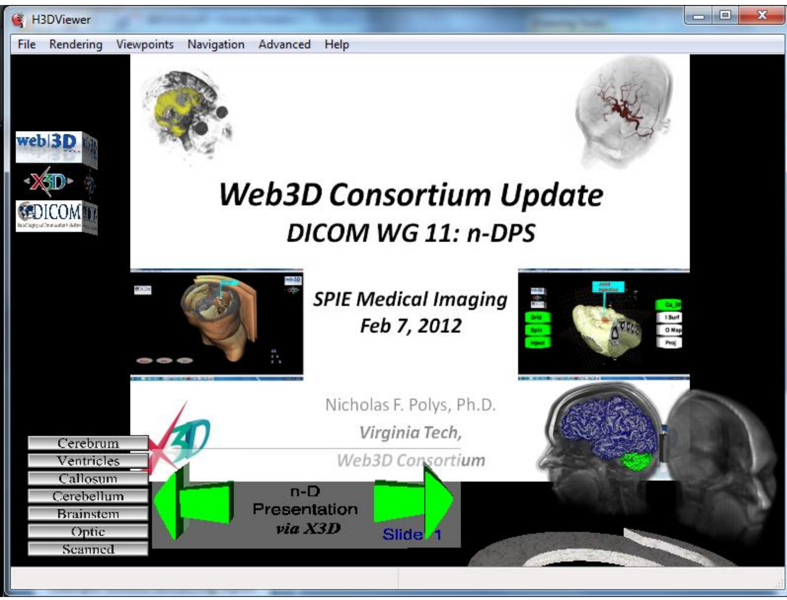
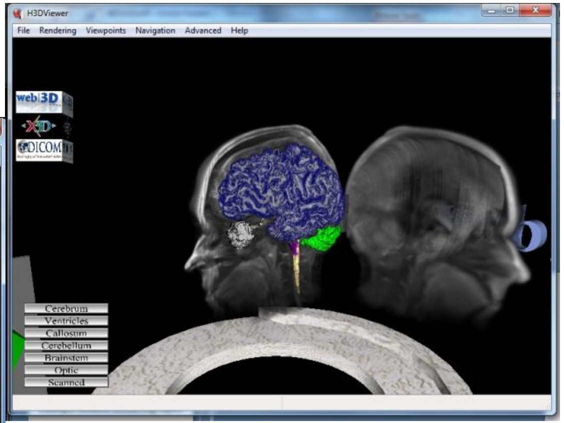
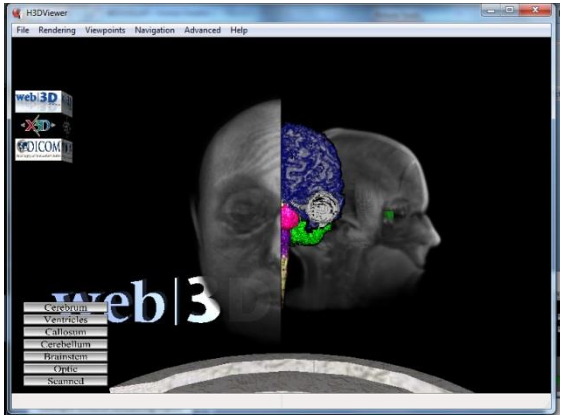
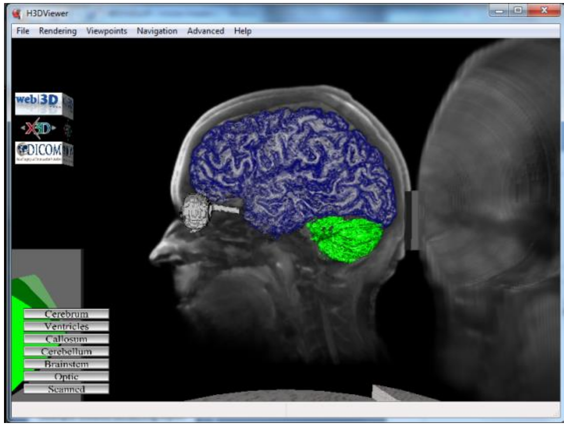
X3D Presentation Demo









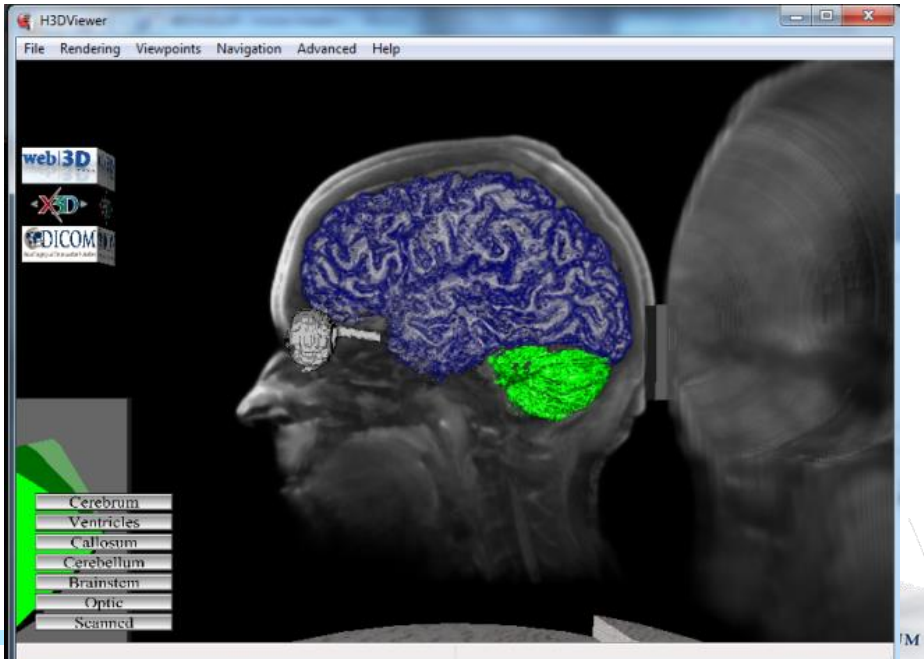
Screenshots

- Nicholas Polys, Andy Wood 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>
```



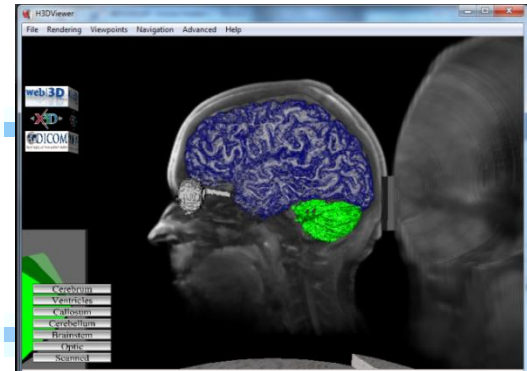
Example Volume Rendering Styles

(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>
```

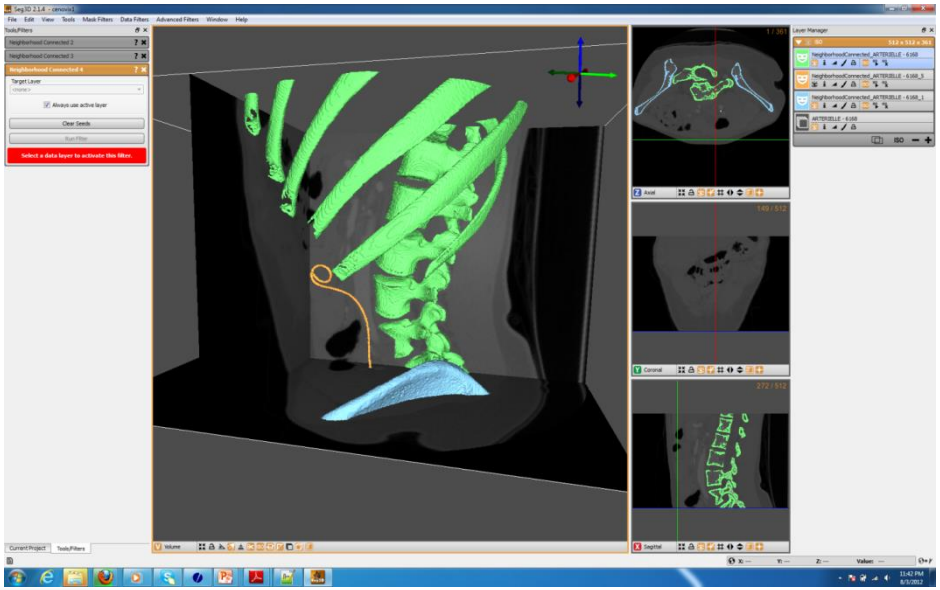


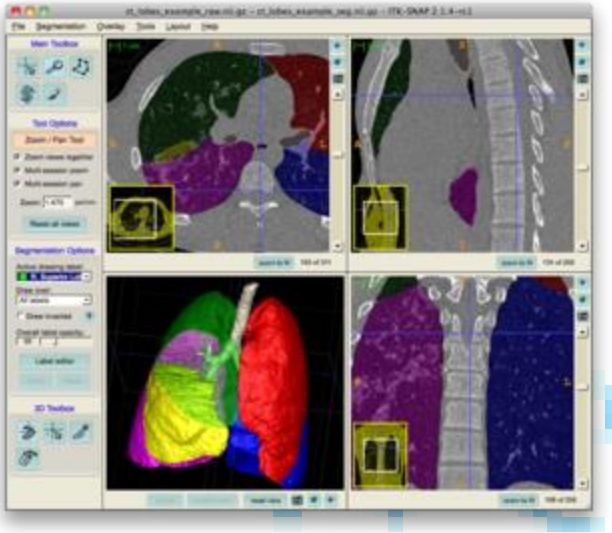
X3D-Edit 3.3

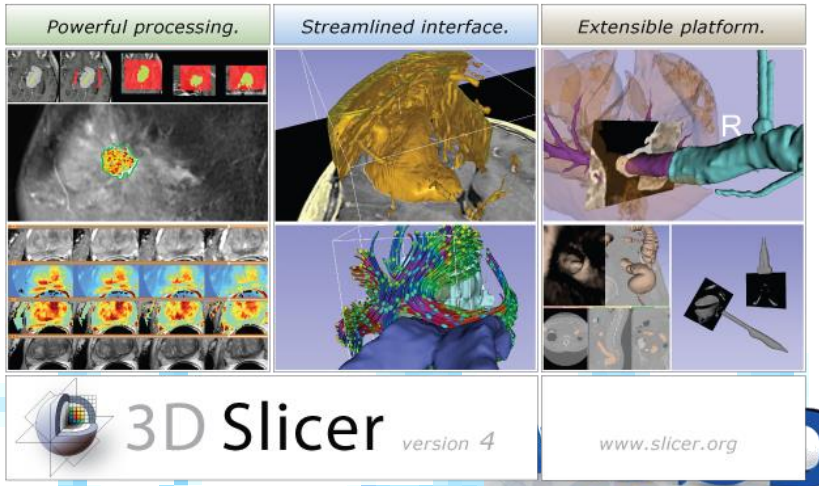
- Structured scene editor
- DTD and Schema includes new Components and Nodes
- Multiple check Validators for quality assurance
- Cross-platform : stand-alone or Netbeans plug-in
- Free!

Use Common Formats, Open Tools

- .nrrd, .dcm
- Seg3d.org
- Slicer.org
- Itksnap.org
- …







DICOM WG11 Progress

- Supp 156 in draft stage includes complementary functionality to specify:
  - Multi-planar and Curved-planar reformatting

- Also lots of places for ‘Semantic Interoperability’
  - Volume Projection (X-Ray) style, OpacityMap (transfer function)
  - Specular light
  - Camera Animation such as flythrough and swivel

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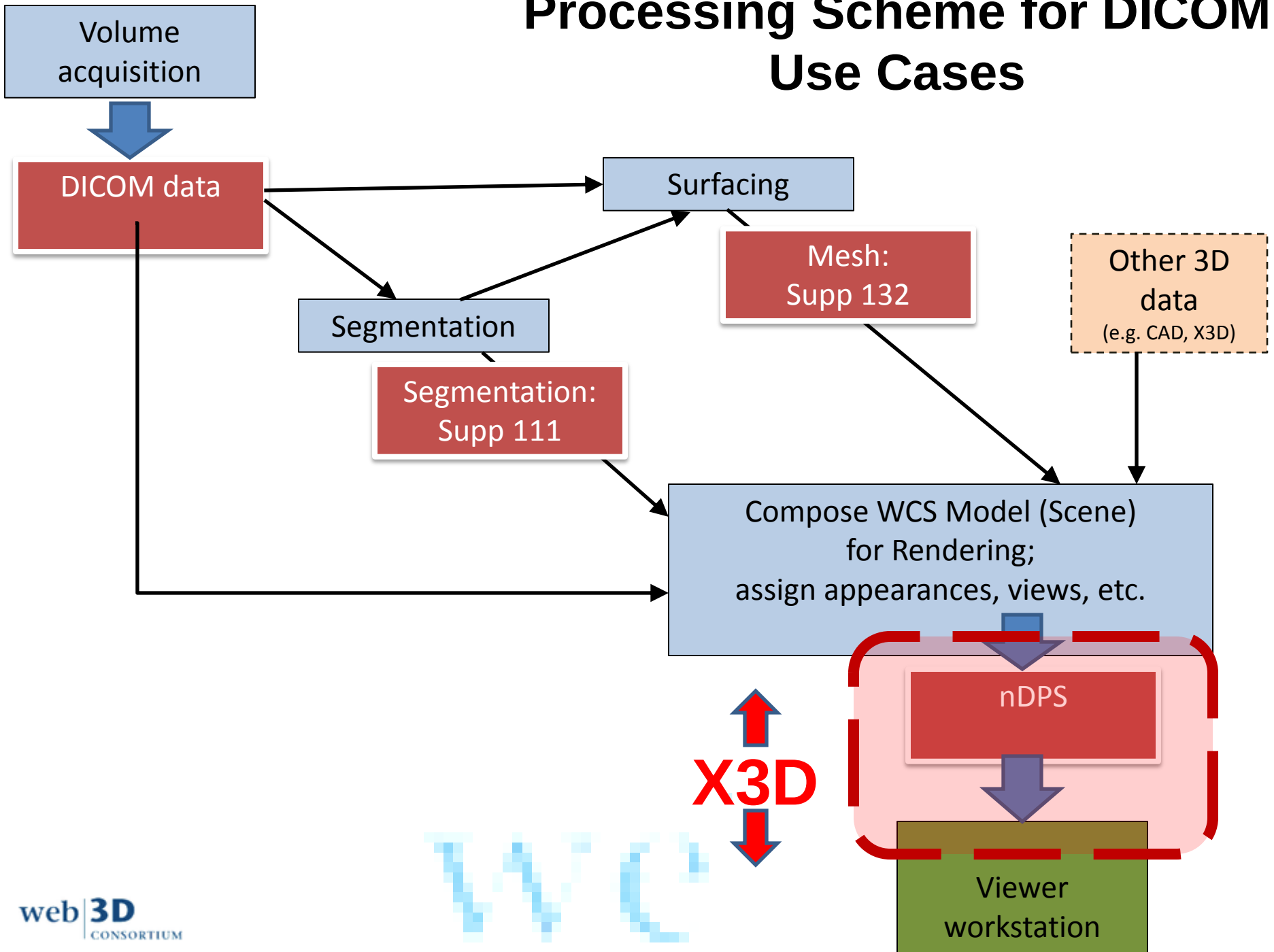
Processing Scheme for DICOM Use Cases



Volume Data Formats

- Raw voxel data (image stack)
  - Requires external metadata
- DICOM (.dcm)
  - Digital Imaging and Communication in Medicine: http://medical.nema.org
- NRRD (.nrrd)
  - Nearly Raw Raster Data: http://teem.sourceforge.net/nrrd
  - Wrapper for raw or compressed image stacks with plain text metadata
  - TEEM library for pre-processing and analysis

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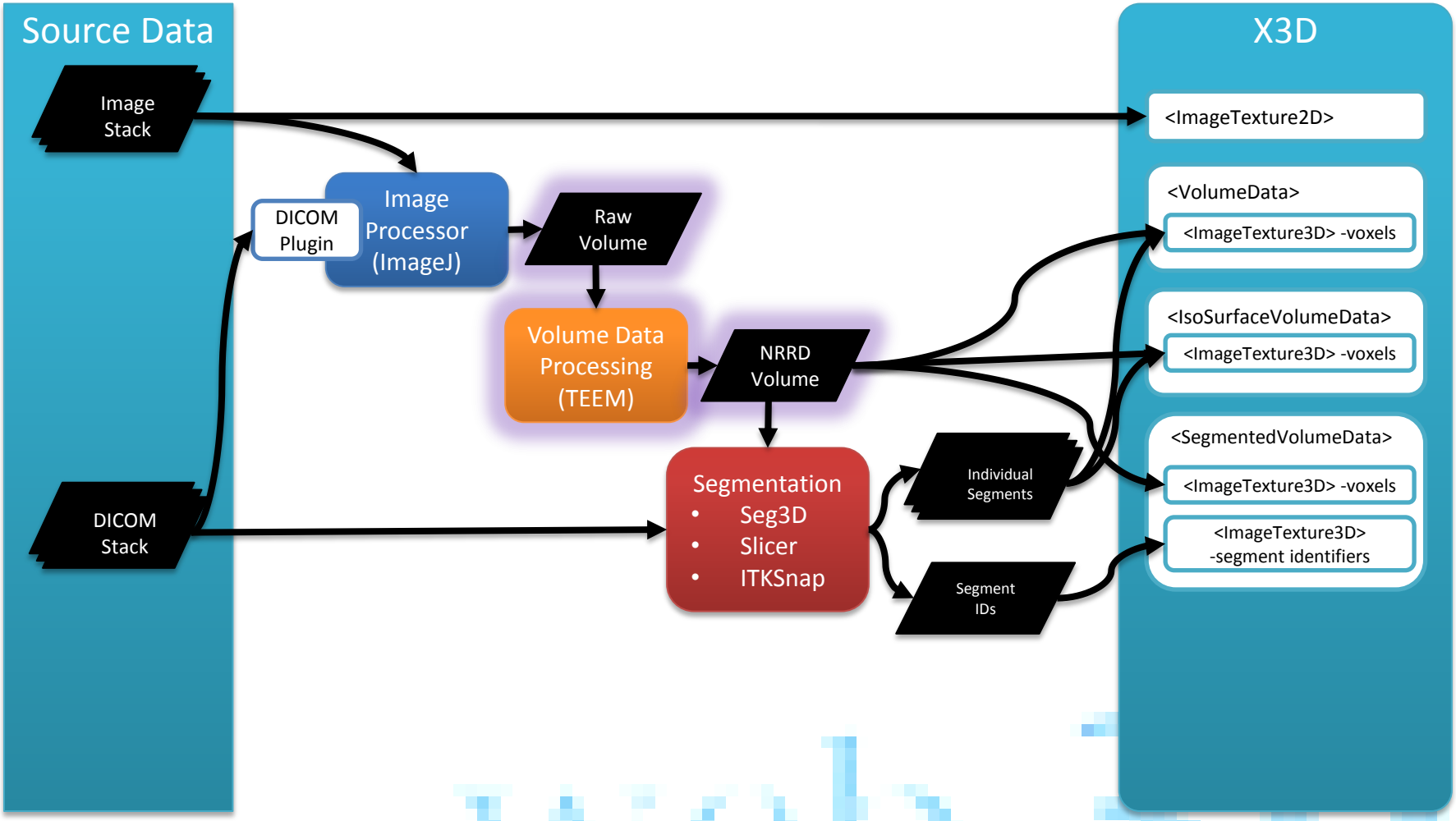
Volume Data


Source Data
Image Stack
DICOM Plugin
Image Processor (ImageJ)
Raw Volume
Volume Data Processing (TEEM)
NRRD Volume
DICOM Stack
Segmentation
• Seg3D
• Slicer
• ITKSnap
Individual Segments
Segment IDs
X3D
<ImageTexture2D>
<VolumeData>
<ImageTexture3D> -voxels
<IsoSurfaceVolumeData>
<ImageTexture3D> -voxels
<SegmentedVolumeData>
<ImageTexture3D> -voxels
<ImageTexture3D> -segment identifiers

Volume Data Formats

- Raw voxel data (image stack)
  - Requires external metadata
- DICOM (.dcm)
  - Digital Imaging and Communication in Medicine: http://medical.nema.org
  - [MORE POINTS HERE]
- NRRD (.nrrd)
  - Nearly Raw Raster Data: http://teem.sourceforge.net/nrrd
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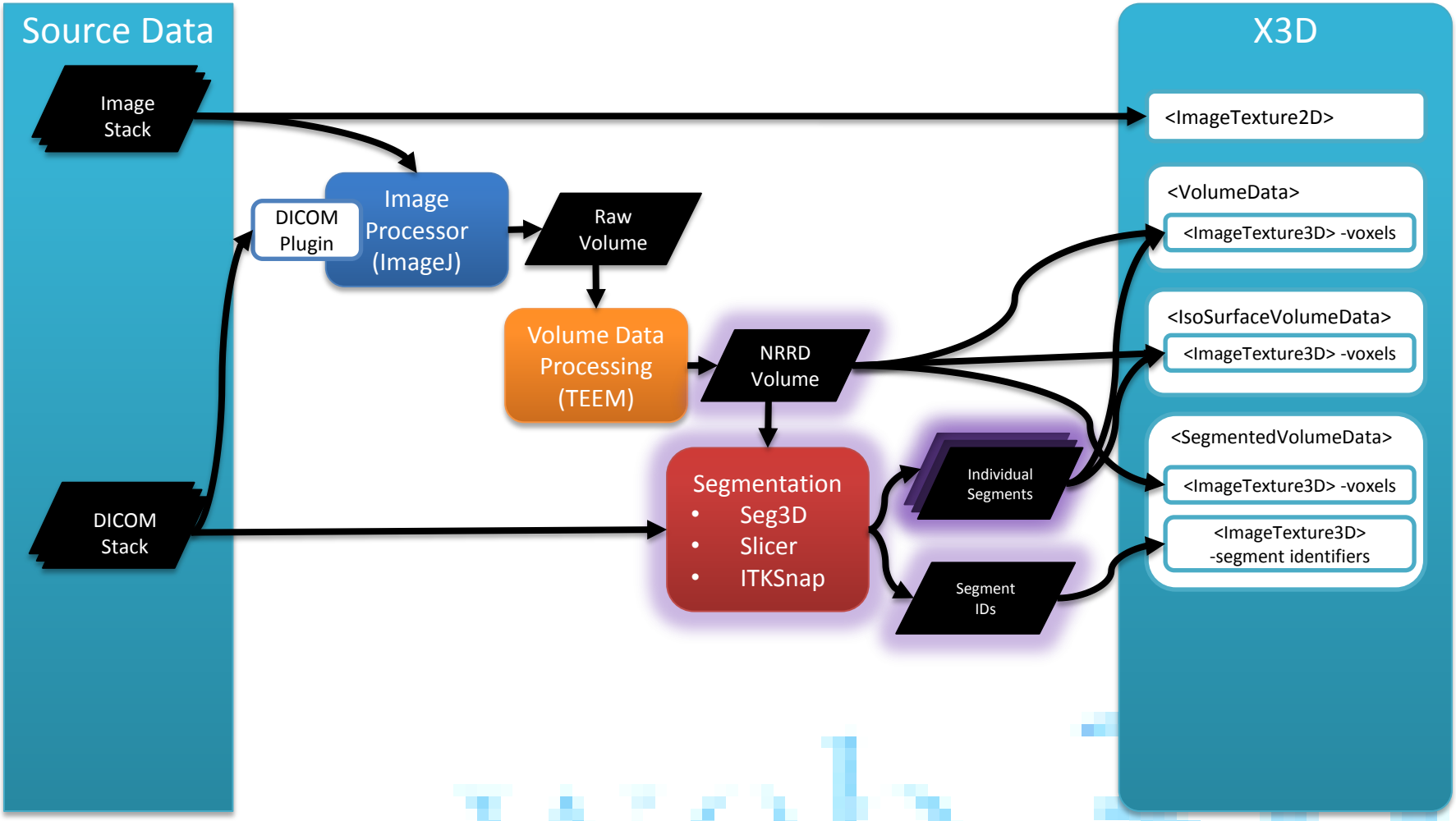
Segmentation



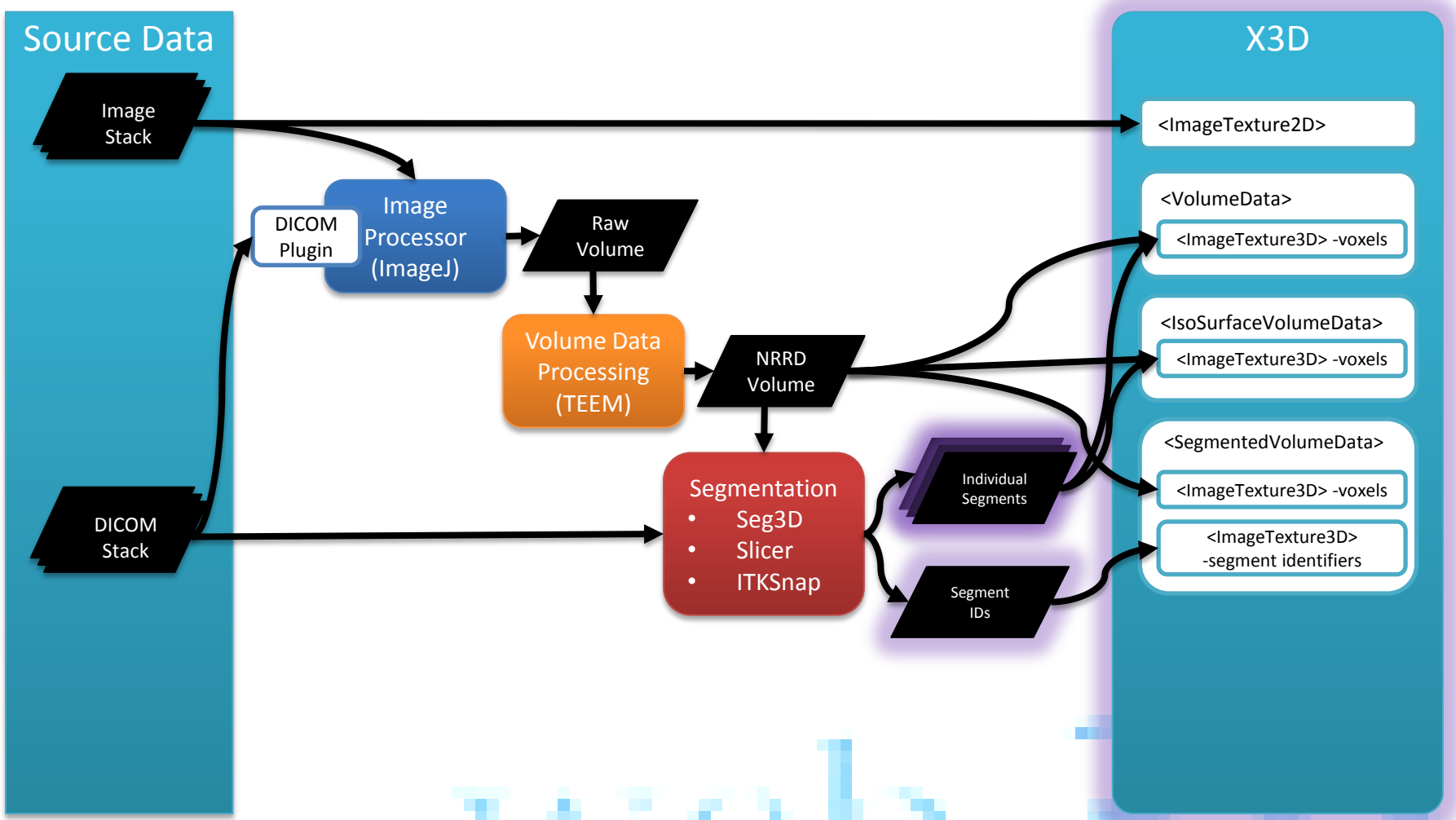
Segmentation

- Transfer functions and rendering techniques are powerful, but not always sufficient
- Segmentation - mark features of interest for special rendering treatment
- Some techniques:
  - Hand segmentation (painting)
  - Threshold (used in many approaches)
  - Volume growing
  - Connected components

Segmentation Tools

- Seg3D
  - Large selection of segmentation algorithms and tools
  - Layered segment masks with multi-layer operations and export flexibility
  - http://www.sci.utah.edu/cibc-software/seg3d.html
- ITKSnap
  - Active contour segmentation (volume growing) and manual tools
  - http://www.itksnap.org/pmwiki/pmwiki.php
- 3D Slicer
  - Volume manipulation and segmentation, with a focus on registration (multiple volumes) and rendering
  - http://slicer.org/

Volume Rendering With X3D



Volume Rendering With X3D

- Volume rendering component added in X3D 3.3
  - [ISO document info here]
- Examples found at: http://www.web3d.org/x3d/content/examples/Basic/VolumeRendering/
- Browsers:
  - H3D (full support): http://www.h3dapi.org/
  - InstantReality (partial support): http://instantreality.org/
- [not sure about officially supported file types, per browser]

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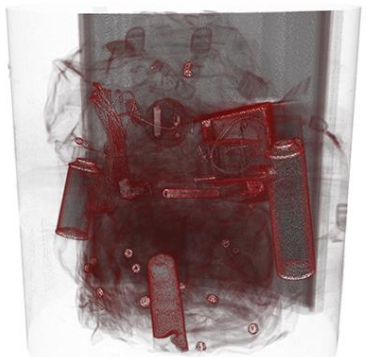
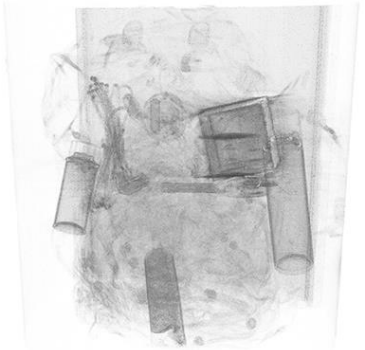
Combining Styles: ComposedVolumeStyle

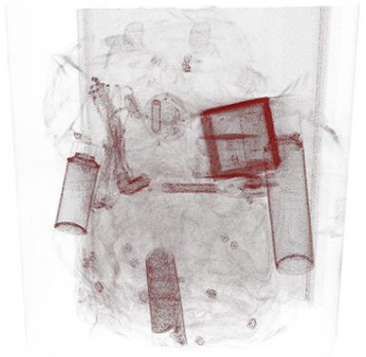
```
<ComposedVolumeStyle enabled='true' ordered='false' containerField='renderStyle'>
        <SilhouetteEnhancementVolumeStyle silhouetteBoundaryOpacity='1'
          silhouetteRetainedOpacity='.1' silhouetteSharpness='10' enabled='true'
          containerField='renderStyle'/>
        <EdgeEnhancementVolumeStyle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



Style1 (Edge Enhance)



Style2 (Silhouette)



Composed Styles

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Multipart Volumes: SegmentedVolumeData

- Requires two textures: voxels (as normal) and segment identifiers for each voxel
- Specify multiple render styles, in identifier/segment order (default is opacity map)
  - If more segments than styles, last style applies to remaining segments
- Individual segments may be turned on or off using “segmentEnabled” field
  - Styles still required to maintain indexing

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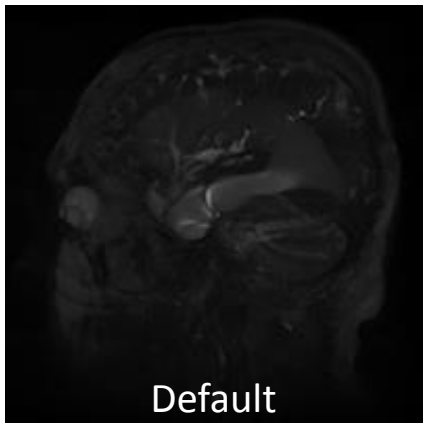
Multipart Volumes: SegmentedVolumeData

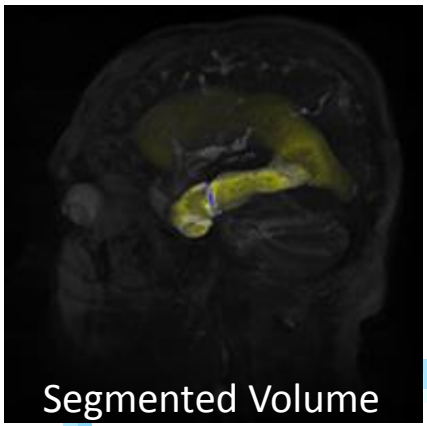
```
<SegmentedVolumeData dimensions='2.304 2.304 1.116' containerField='children'>
  <ImageTexture3D containerField='voxels' repeatS='false' repeatT='false' repeatR='false'
    url=' "mri_ventricles.nrrd" '/>
  <ImageTexture3D containerField='segmentIdentifiers' repeatS='false' repeatT='false' repeatR='false'
    url=' "mri_ventricles_segment.nrrd" '/>
  <OpacityMapVolumeStyle enabled='true' containerField='renderStyle'/>
  <ToneMappedVolumeStyle enabled='true' coolColor='0 0 1 0' warmColor='1 1 0 0'
    containerField='renderStyle'/>
</SegmentedVolumeData>
```

Voxels

Segments

Styles

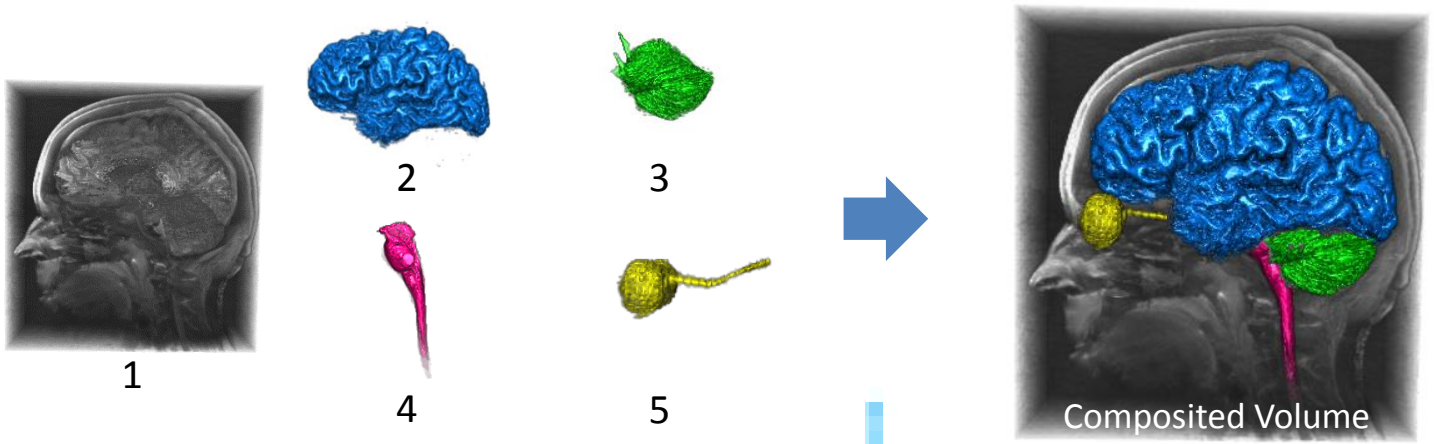




Multipart Volumes: Multiple Volumes

```
<VolumeData dimensions='.75 1 1' >
Segment1    <ImageTexture3D containerField="voxels" url='"./Segments/masked-halfhead.nrrd"'/>
Style 1     <OpacityMapVolumeStyle />
</VolumeData>

<VolumeData dimensions='.75 1 1' >
Segment2    <ImageTexture3D containerField="voxels" url='"./Segments/masked-cerebrum.nrrd"'/>
            <ShadedVolumeStyle lighting="TRUE" shadows="TRUE" >
Style 2                 <Material diffuseColor='0 .5 1' specularColor='1 1 1' ambientIntensity='0.8' shininess='0.08' />
            </ShadedVolumeStyle>
</VolumeData>
```



Multipart Volumes: BlendedVolumeStyle

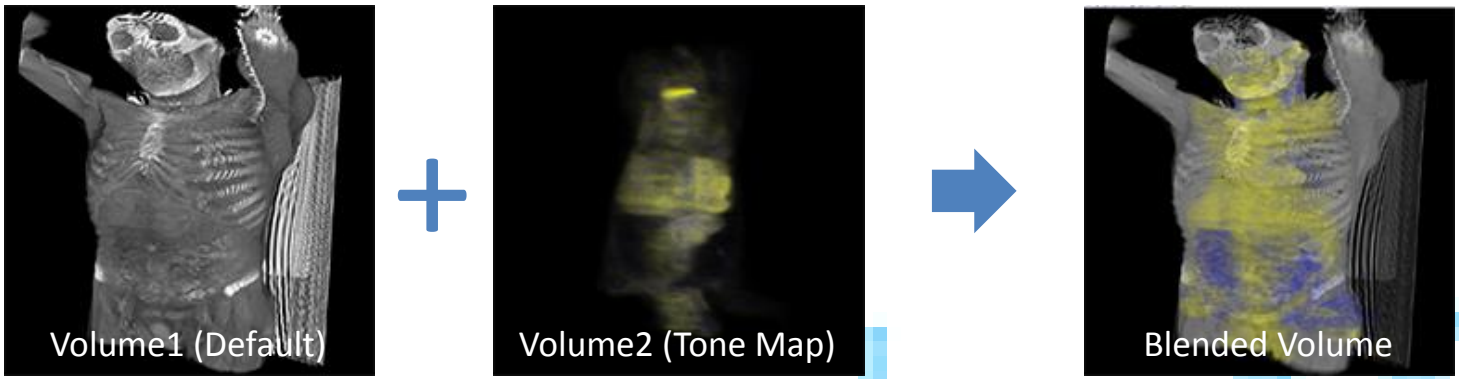
```
<VolumeData dimensions='512 512 452' containerField='children'>
        <BlendedVolumeStyle weightConstant1='0.51' enabled='true' weightConstant2='0.5'
          weightFunction1='CONSTANT' weightFunction2='CONSTANT' containerField='renderStyle'>
          <ToneMappedVolumeStyle enabled='true' coolColor='0 0 1 0' warmColor='1 1 0 0'
            containerField='renderStyle'/>
          <ImageTexture3D containerField='voxels' repeatS='false' repeatT='false'
            repeatR='false' url=' "internals.nrrd" '/>
        </BlendedVolumeStyle>
        <ImageTexture3D containerField='voxels' repeatS='false' repeatT='false' repeatR='false'
          url=' "body.nrrd" '/>
</VolumeData>
```

Default Style1

Style2

Volume2

Volume1



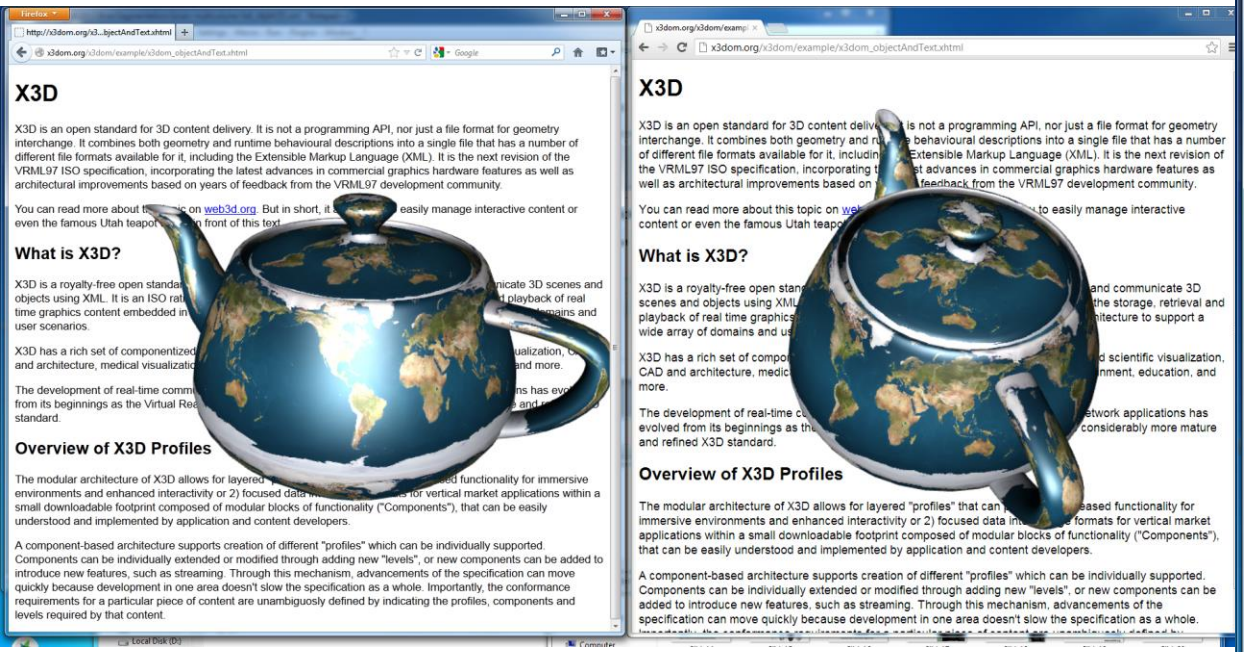
Examples

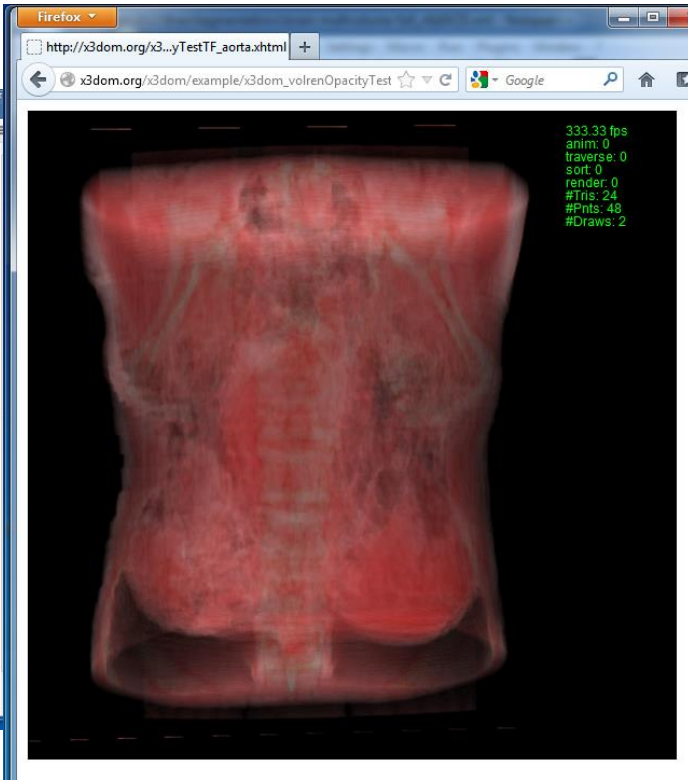
- DICOM
- Cell Image database
- Fossils
- …

X3DOM.org

Firefox

Chrome





HTML 5 with Web3GL and X3D!

Volume Rendering (MedX3DOM)

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MedX3DOM

- Implementation to support advanced medical visualization on the Web without plugins
- MEDX3D standard implemented into the X3DOM framework
  - MEDX3D: extension of the X3D ISO standard to support advanced medical visualization functionality
  - X3DOM: framework for integrating and manipulating X3D scenes as HTML5/DOM elements

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Methodology for MedX3DOM

Node generation for two components

- Texturing3D
  - X3DTexture3DNode
  - ComposedTexture3D
  - ImageTexture3D
  - PixelTexture3D
  - TextureCoordinate3D
  - TextureCoordinate4D
  - TextureTransformMatrix3D
  - TextureTransform3D
  - ImageTextureAtlas

- VolumeRendering
  - X3DComposableVolumeRenderStyleNode
  - X3DVolumeDataNode
  - X3DVolumeRenderStyleNode
  - BlendedVolumeStyle
  - BoundaryEnhancementVolumeStyle
  - CartoonVolumeStyle
  - ComposedVolumeStyle
  - EdgeEnhancementVolumeStyle
  - IsoSurfaceVolumeData
  - OpacityMapVolumeStyle
  - MPRVolumeStyle
  - ProjectionVolumeStyle
  - SegmentedVolumeData
  - ShadedVolumeStyle
  - SilhouetteEnhancementVolumeStyle
  - ToneMappedVolumeStyle
  - VolumeData

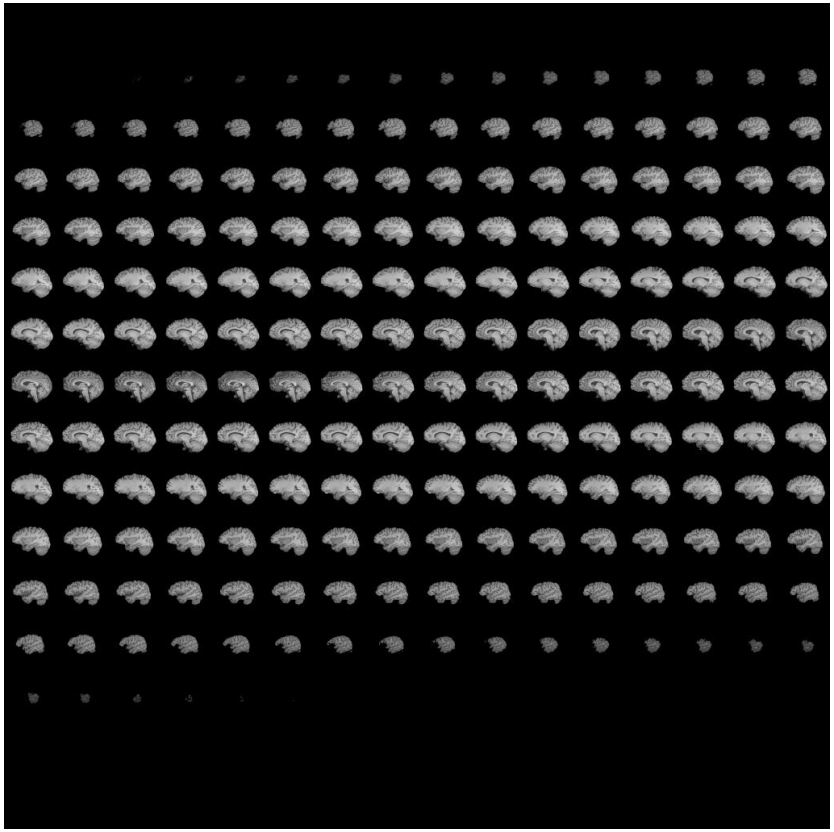
Implemented/In progress
Defined
Not implemented
Abstract

Atlas Image Type

- Atlas
  - Composed image
  - Parameters
    - Number of slices
    - Number of rows
    - Number of columns

The texture atlas is the mosaic of all the slices of a volume in one image, the order of the images is given by the rows and columns.

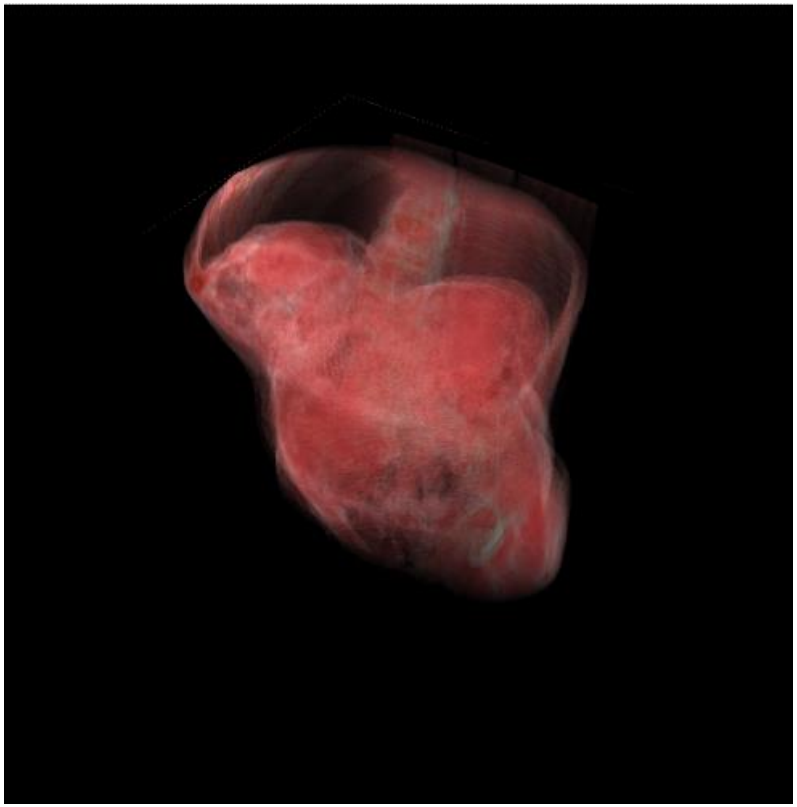
Ex: Brain Atlas Image



Aorta Example

http://x3dom.org/x3dom/test/functional/volrenOpacityTestTF_aorta.xhtml

```
<X3D xmlns='http://www.web3d.org/specifications/x3d-namespace'
      showStat='true' showLog='true' width='500px' height='500px'>
  <Scene>
    <Background skyColor='0.0 0.0 0.0'/>
    <Viewpoint description='Default' zNear='0.0001' zFar='100'/>
    <Transform>
     <VolumeData id='volume' dimensions='4.0 4.0 4.0'>
       <ImageTextureAtlas containerField='voxels'
      url='media/volume/aorta4096.png' numberOfSlices='96'
      slicesOverX='10' slicesOverY='10'/>
       <OpacityMapVolumeStyle lightFactor='0.02'
      opacityFactor='0.4'>
        <ImageTexture containerField='transferFunction'
      url='media/volume/transfer/transfer.png'/>
       </OpacityMapVolumeStyle>
     </VolumeData>
    </Transform>
  </Scene>
 </X3D>
```



DICOM, NRRD, RAW Format??

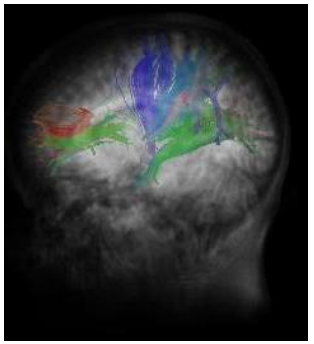
- Javascript is very slow to process binary data
- The loaders of this kind of volume data are based in C and the conversion or reimplementation is difficult
- Other types of volume formats exists, like MHD, NetCDF, …., imposible to implement all.
- MEDX3DOM is for the web, using web formats

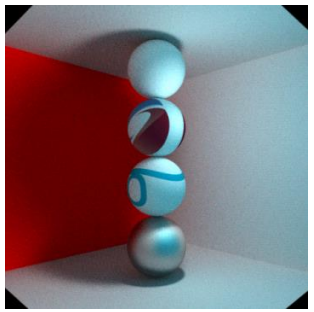
MEDICAL IMAGING

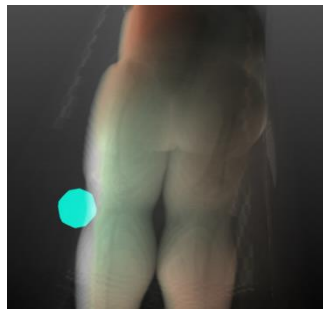
- DICOM format is ´´the´´ standard for medical imaging, but internally is a container of several kind of data, sound, 2D images, 3D images, metadata,etc.
- WADO: It is a webservice which provides medical images through the web stored in a PACS server.
- MEDX3DOM: support WADO (Web Access to DICOM Objects)

MEDX3DOM Future …

- Next improvements
  - Integration Combination with mesh models
  - Implementation of different styles (MIP, X-Ray, Composed …)
  - Lighting (Phong, Global illumination …)
  - Animation (4D timesteps, video, flow animation …)
  - Data transfer optimization (streaming, compression,…) … collaborative visualization







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Next Steps

- MedX3DOMdevelopment : VolumeStyles,
- Devlop new Specs:
  - Haptics
  - Soft-body physics
  - Annotation
- Anthopometric Site references, H-anim
- DICOM

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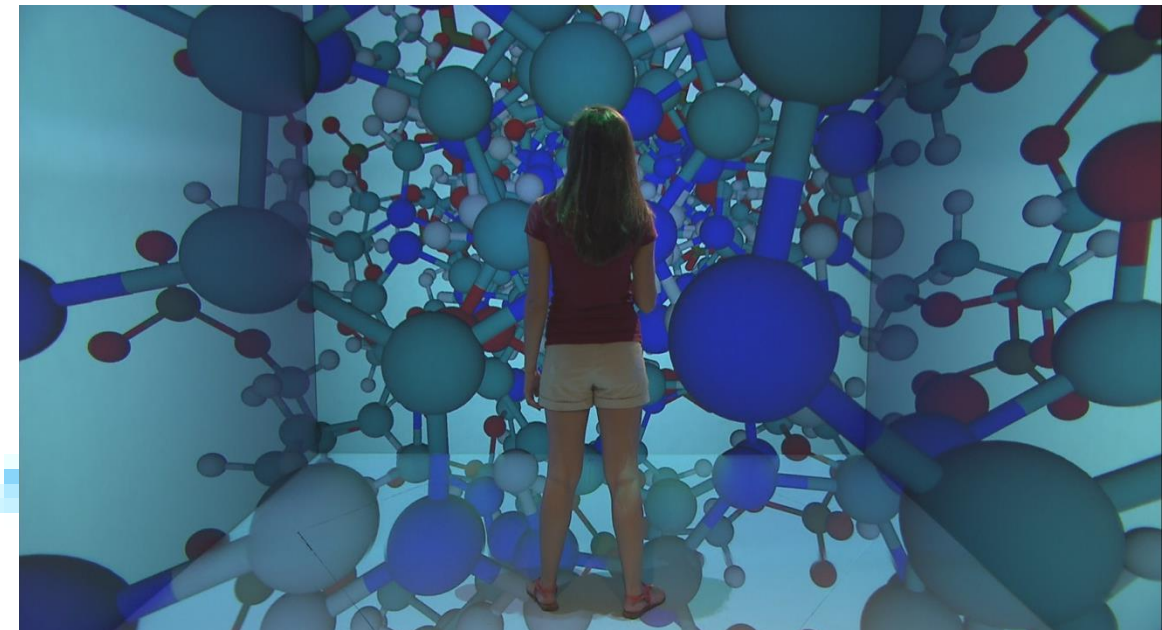
Web3D Chapters

- Korea



Join Us!

Professional *and* Institutional opportunities!

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www.web3d.org

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