Portable and Interoperable Views of Medical Image Data with ISO Extensible 3D (X3D)

Opportunities Whitepaper

Web3D Consortium, www.web3d.org
November 2012

Executive Summary

The Extensible 3D scene graph, X3D (ISO/IEC 19775), provides an expressive and durable platform to build interactive rich-media 3D visualizations. Working above any specific rendering library, X3D provides a powerful set of abstractions to compose meshes, appearances, lighting, animations, viewpoints, navigations and interactions. From laptops to immersive VR installations to mobile devices, X3D delivers interoperable 3D at web enterprise scale. The newest revision of X3D: version 3.3 (2012) includes new components and functionality for reproducible, platform-independent volume rendering.

From its original US TATRC-funded project for advanced medical visualization functionality and medical data exchange, the Web3D Consortium's Medical Working Group (MWG) has specified and demonstrated cross-platform volume rendering styles (i.e., transfer functions), segmentation and ontology integration (e.g. SNOMED). From clinical DICOM scans and reviews of patients to advanced microscopy and 500 million year old fossils, the VolumeData and VolumeRenderStyle nodes of X3D 3.3 provide an expressive, open and royalty-free basis to reproduce rich cross-platform visualizations.

With the technological foundations in place for web-enabled presentations of both polygonal, volume and meta data, it is now time to activate these new extensions and value chains for the healthcare and research enterprise. We propose a two-pronged program to leverage this prior work into new workflows as well as to further extend the X3D specification to address newly-realized clinical requirements. In this whitepaper, we outline these new opportunities and describe strategic tasks to deliver new efficiencies in tool deployments as well as new ISO standard specifications.

The Web3D Consortium and the international standards community stand ready to evolve and build these technologies for their broadest impact across industries. Specifically, new opportunities for development (2013-2015) are:

Deploying ISO X3D 3.3:

- Open-source MEDX3DOM implementation for HTML5 – X3D MedicalInterchange Profile in X3DOM framework
- Official Medical Interchange Profile Conformance Suite
- X3D 3.3 Volume and segmentation exporter for VTK/ITK toolkits

Extending X3D *(open-source implementation, ISO Documents and Conformance Suites):*

- Annotation Component – provides consistent visual association of semi-structured text in relation to 3D regions of interest
- Curved-Planar Re-projection – to provide flexible support in projecting a volume view along a 3D line (e.g. to obtain a linear measurement of a curved objects such as a vesicle or spine)
- Haptic and Soft-body Physics Components – support the meshing and physics models for patient-specific human simulation and training

For more information, see the Web3D Medical Working Group's Public Wiki:
http://web3d.org/x3d/wiki/index.php/X3D_Medical

Images by Virginia Tech Visual Computing

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Introduction

The International Standards Organization (ISO) standard for 3D graphics over the Internet is Extensible 3D (X3D), which is maintained and developed by the Web3D Consortium. The open and royalty-free ISO standard scene graph has evolved through 15 years of hardware development and software boom-busts and remains the greatest common denominator for communicating real-time interactive 3D scenes over the web. With dozens of implementations across industries and operating systems, X3D specifies this scene graph in layers of functionality, known as 'Profiles' and several encodings, including binary and XML. In this whitepaper, we provide a roadmap for the research and development of open standards information ecosystems targeting ***reproducible volume presentations for the healthcare enterprise.***

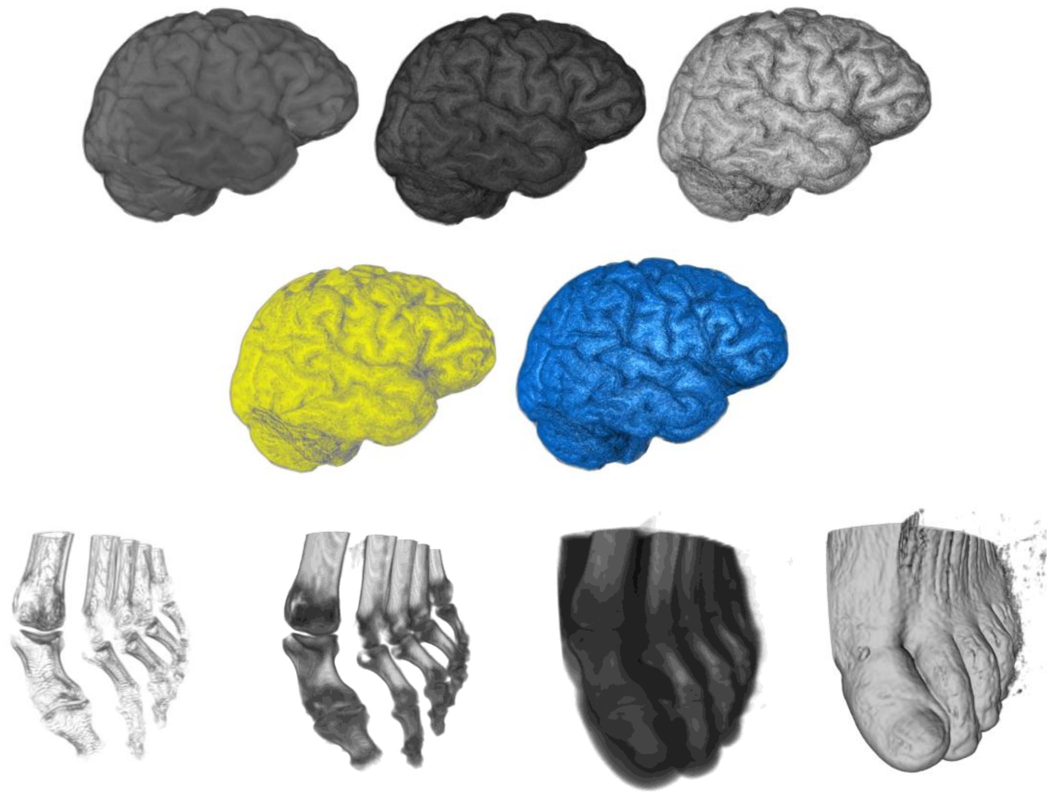

Figure 1: X3D 3.3 Enhancement RenderStyles applied to a brain MRI;
top row: a) Opacity-mapped, b) Edge Enhanced, c) Cartoon; middle row: d) Tone-mapped, e) Shaded style
bottom row: f) Threshold, g) Projection, h) OpacityMap, i) IsoSurfaceVolumeData

The reproduction of volume-rendered presentations of medical image data across platforms and the healthcare enterprise presents several challenges, especially due to data and view incompatibilities and lock-in to proprietary systems. However, explicit 3D visual presentations of medical images can provide significant advantages because this type of rendering is more truly representational of the object being imaged (the human body), it is a more intuitive and easily-read format. It is increasingly common to render a three dimensional (3D) model from a CT, MRI, PET and X-Ray scan to better interpret the size, orientation and other spatial relationships of the patient's anatomy as necessary for diagnosis and therapy.

Until recently, there was little hope of interoperability for interactive 3D and 4D presentations to break out of the hospital PACS and to be archived and shared across the enterprise. With the continual advancement in computing and graphical power over the last decade, specialized workstations and software capacity has become available to display this type of 3D imaging on a common laptop. It is an imminent future when the handheld tablets on the market are capable of sustained hardware-accelerated graphics performance.

Domains

X3D's Volume rendering capabilities were originally designed to improve the accessibility of 3D reconstructions of CT, MRI, PET or ultrasound studies outside the radiology suite. The expressive and compose-able rendering styles of X3D provide support for the isolation of different structures or systems in the volumes (segmentations), and the registration / fusion of two or more segmented volumes (blending). These functionalities have found fertile ground in several verticals beyond medical. In this section, we describe the X3D value proposition across a number of crucial use cases including ***Custom Prostheses, Surgical Planning, Informed Consent, Anatomy Education, Surgical Education, Radiation Therapy, Microscopy, Geology, Paleo-biology, Non-invasive Sensing*** and Weather.

Custom Prostheses

Matching generic prostheses to a specific patient can be difficult prior to surgery due to projection errors on plain X-rays, unforeseen anatomical limitations or unpredicted complications during surgery. Total joint surgeries require a size inventory of prosthetic products be available as size predictions have nominal accuracy. Specialized prostheses require custom fabrication and therefore would need volume rendered patient specific datasets to compute exact dimensions. The open standard enables the use of custom prostheses on a wider scale with its support for CAD models, meshes and different imaging modalities. This convergence provides confidence in the patient dataset and efficiencies in the 3D printing and manufacturing pipelines.

Surgical Planning

Complex surgical cases require planning that includes visualization of the approach, tissue exposure and execution of the defined procedure. If thin client plus server or advanced visualization software is not available to the surgeon, they may be relegated to traditional cross sectional scan views or snapshots of volume rendered images. Using the capabilities of X3D, surgeons can analyze patient volumetric data from their office or home computer to plan their operation, make measurements and label objects. This technology would be relevant to all areas of surgery, especially vascular, orthopedics, head and neck, plastics and cardiothoracic subspecialties. This functionality is also valuable for dental implant planning and 3D cephalometric analyses for orthodontic and orthognathic surgical planning.

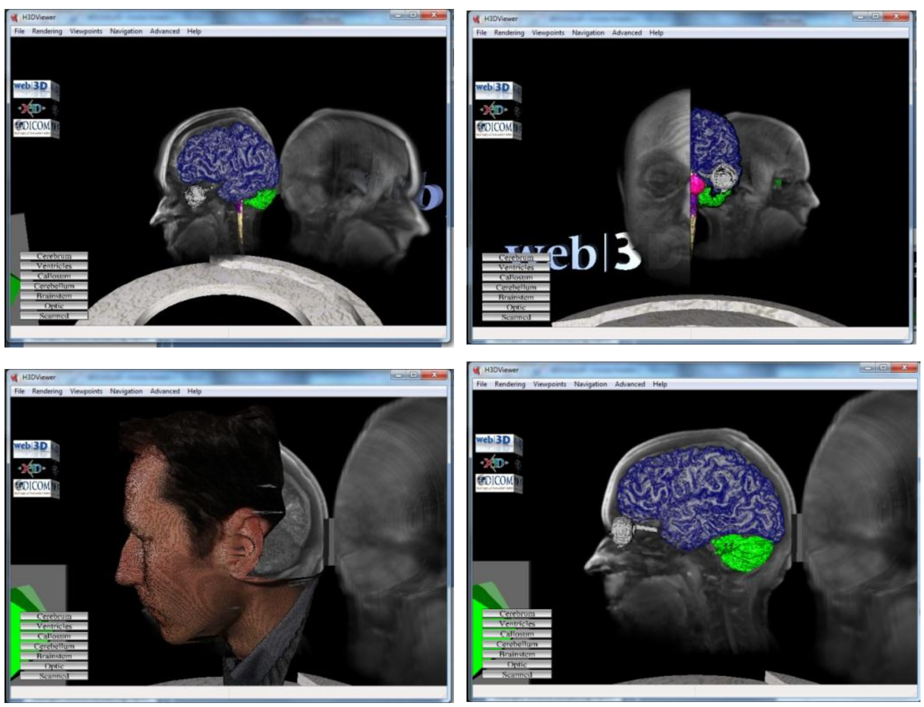

Figure 2: X3D 3.3 Segmentation application of a brain MRI and a patient face scan

Informed Consent

Physicians are required by law to inform patients of the mechanics, risks, benefits and alternatives of invasive procedures and to document this exchange in the form of a signed inform consent form. Frequently physicians find themselves taking significant time to explain more complex procedures and their patients leaving the office without fully understanding the actual procedure. An open, royalty free standard enables inexpensive and free tools to be available to physicians and patients for understanding and visualizing their medical condition. X3D also allows sophisticated simulations so that animations of the actual procedure on the patient's data can be displayed for further clarity.

Anatomy Education

Anatomical coursework is difficult in part due to inadequate resources for learning. Cadavers, although arguably the best way to learn anatomy, are always in short supply. Dissection teams composed of several members and limited access are factors that contribute to less time for an individual to explore anatomical relationships and tissue characteristics independently. Textbooks are constrained to 2D presentations, and although software is available with interactive 3D displays, many times the data is illustrative rather than real. Although illustrative visualization is important in education, the ability to visualize volumetric representations of real data, and therefore the ability to visualize pathology as well as normal anatomical variants, is an important part of building an anatomical knowledge base. The open standard makes inexpensive or freely available tools available to students of anatomy to explore real data sets to understand these subtleties without having to have access to an expensive computer or high end server.

Surgical Education

The surgical modeling and simulation community is mostly fragmented with numerous surgical simulators, physiologic models and devices available but no significant level of interoperability. Still no accepted methodology exists to compare features and functionality or to begin to assess surgical skill for the benefits of training and certification. To help realize the interoperability vision, several factors must converge including sponsor and contract requirements for open-source releases of simulation engines and a standardized file format. Advances in networked haptics and web based surgical simulators make the open standard of X3D a natural fit with its support for 3D medical image data sets.

Radiation Therapy

Cancer is becoming more prevalent as the population ages. Radiation therapy is an important modality for therapeutic intervention in many forms of cancer. Treatment with this modality is labor intensive and requires significant planning to predict beam reach and path, gantry position and path and beam intersection with pathologic tissue. Multiple applications need to be accessed to complete this planning but some of the questions aren't even answered (prediction of collision of gantry with patient, bed, floor). This can lead to slower turnaround times with an always overbooked radiation therapy device. Using X3D as a standard for 3D medical images, we can realize an integrated solution and complete preplanning package using patient and machine specific data to predict collisions and analyze beam penetration customized for the individual.

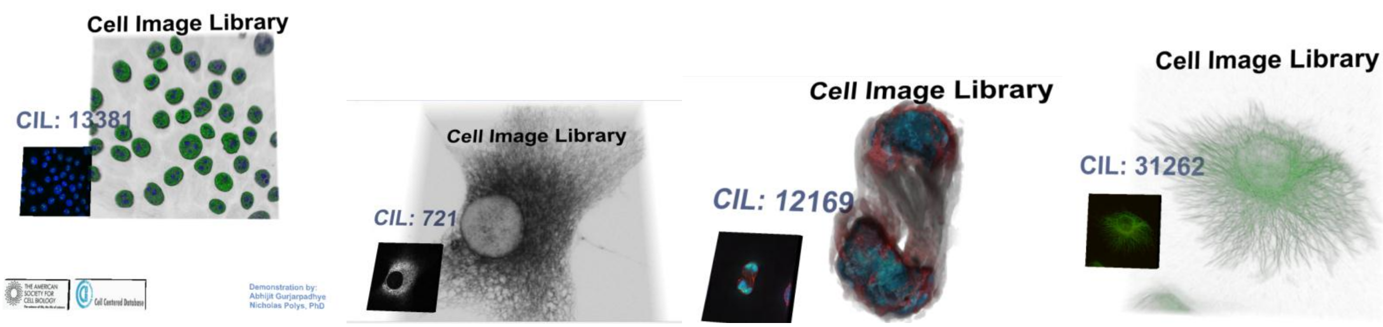

Figure 3: X3D 3.3 segmentations and renderings of multi-channel microscopy z-stacks: *http://cellimagelibrary.org*

Microscopy

There is a huge body of 3D volumetric data from the biology community. Acquisition of data at the micro scale shows cellular structures and populations. Several different staining techniques, or 'channels' are used, to track molecule's activity within the cell; this is a high-impact area since clinical and high-throughput imaging for drug discovery can benefit from X3D's interoperability of data, metadata and 3D views.

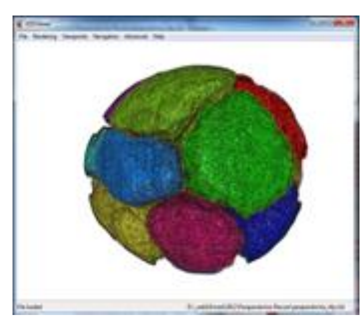

Figure 4: Parapandorina in X3D 3.3

Geology

A host of sensing modalities are used to profile and characterize underground structures. Whether it is for water or oil discovery or examining bedrock for structural support, the data sets in geophysical measurements are predominately volumetric.

Paleo-biology

In order to study the morphology and evolution of life on earth, scientist use micro CT imaging to scan rock samples and reconstruct fossils' shapes. For example, using X3D volume rendering, we have discovered new properties of the cell nuclei in the 550 million year old Parapandorina specimen.

Non-Invasive Scanning

The security of our buildings and transportation sectors relies on non-invasive imaging. Baggage, persons, mail and shipping containers are all subject to visual inspection. Volumetric data is also captured to examine and evaluate the structural integrity of bridges and parts.

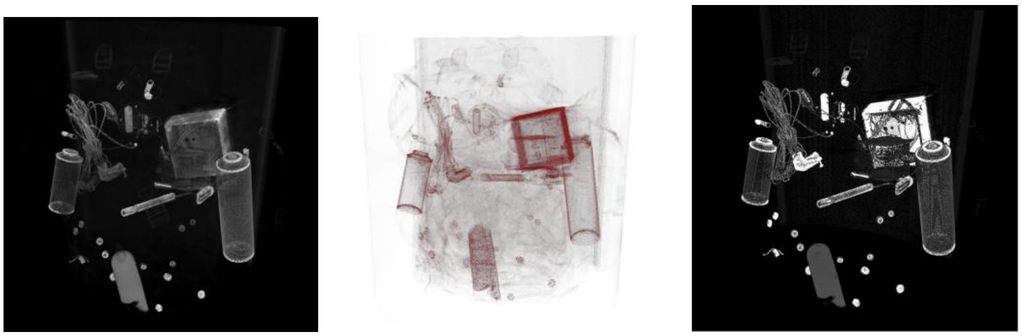

Figure 5: Three X3D 3.3 EnhancementStyles on the TSA backpack example

Weather

In addition, at the urban and geographic scales, volumetric data and volume rendering techniques can be used; for example, from the output of high resolution Air Quality models; Web3D members have demonstrated an application that shows pollution levels over time in the context of an interactive 3D city model. Other example of such application in the meteorology visualization is the weather Doppler radar. Raw data output coming from the weather radar has been visualized using volume rendering techniques.

Platforms: Present and Future

The ISO X3D 3.3 Volume and 3DTexturing Components are implemented in H3D (cross-platform, open-source: *H3D.org*) and InstantPlayer (cross-platform, free: *InstantReality.org*) rendering engines. Our members have demonstrated X3D pipelines with DICOM data, and with several free and open-source tools including ImageJ and segmentation packages including Seg3D, Slicer, and ITK-Snap (Figures 1-5). While the Web3D Consortium has built and certified several engines for conformance to the Interchange Profile, it remains to develop a package for the version 3.3 Medical Interchange Profile. A conformance suite will increase the reliability and adoption of Medical X3D not only in clients, but also in tools.

The World Wide Web Consortium (W3C) has specified HTML5, which includes the Canvas3D tag for native hardware-accelerated 3D as part of the web page. With WebGL and Javascript client code, the X3D scene graph and events can be integrated without a browser plug-in (*X3DOM.org*). At the Web3D 2012 and SIGGRAPH 2012 conferences, VicomTech-IK4 (ES) and Fraunhofer IGD (DE) demonstrated MEDX3DOM, a work in progress implementation to support advanced medical visualization on the Web without plugins, which can render X3D 3.3 VolumeRenderStyles with HTML5 and WebGL; WebGL 1.1 is coming, and with its new GL shader structs, promises to make this integration even more efficient.

DICOM is the medical industry standard for data exchange. Since 2008, the Web3D Consortium has worked with DICOM Working Groups 11 and 17 on the semantic interoperability (Display Standard) of DICOM and X3D including meshes, segmentations, and scene graphs. Supporting additional DICOM requirements such as Annotation and Curved-Planar Re-formatting will require further development and extension to the X3D specification. While demonstrated in H3D, Haptic and soft-body physics support will also require work to develop as a common and official extension to the X3D specification.

Summary

As the cost of CT, MRI, Ultrasound and PET scans decreases and the practice of medicine becomes increasingly noninvasive, the volume of medical images will increase significantly. These images can be most easily interpreted by representing anatomy as it exists in the real world, i.e. in three dimensions. 3D radiography will move from its current niche application space to the mainstream and will become the baseline study in everyday clinical care.

Without the ISO X3D standard for displaying this data in 3D, the medical visualization field, both academic and commercial, remains fragmented. This results in significant duplicated efforts in creating methods of volumetric rendering, registration and segmentation, and the emergence of multiple proprietary file formats, which restrict data sharing and collaboration. Further, proprietary file formats, software and hardware platforms are not easily accessible due to intellectual property, cost and technical constraints; however, the reproduction of medical image presentations across the healthcare enterprise is crucial.

X3D has proven to be a robust and extensible presentation standard to improve interactive visual access to volume and medical image data and clinical ontologies. Strategic investment in the six task areas outlined above will bring its benefits to more institutions, physicians and patients. Focusing on **X3D Medical Interchange Deployment** and **X3D Extensions** can bring the full power of X3D to bear and improve care quality, efficiency and outcomes. The creation of open workflows and mobile HTML5 clients for 3D display of medical imaging data will stimulate innovation and lower the barrier to entry for clinicians, students and the layman alike.

The proposed standardization has more far reaching effects in that the imaging data is used not only for diagnosis and treatment, but as source material in physiological and surgical simulators. The surgical simulation field has traditionally been a mosaic of parallel efforts that produce cutting edge simulations of specific organ systems, specific organs or general tissue dynamics which are isolated products that cannot communicate with each other. To align these efforts so that the ‘best of breed’ organ or system-specific models can be brought together and we can begin to realize a truly computational representation of a human being, standards such as X3D for 3D representation of medical imaging data must be in place. Additional extensions to this standard will enable simulators to conform to approved specifications and allow more valid comparisons between them when attempting to judge their fidelity and utility.

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