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X3D: Extensible 3D Graphics Standard

Extensible 3D (X3D) is the open standard for Web-delivered three-dimensional (3D) graphics. It specifies a declarative geometry definition language, a run-time engine, and an application programming interface (API) that provide an interactive, animated, real-time environment for 3D graphics. The X3D specification documents are freely available, the standard can be used without paying any royalties, and numerous implementations are available.

BACKGROUND

MOTIVATION

It has been obvious since the late 1990s that a common, standardized format was needed for 3D graphics. Companies like ActiveWorlds, Cult3D, and MetaStream created browsers that would only display 3D content created for that particular browser. By the early 2000s, those companies were going out of business. The lessons learned by the early companies were that a common standardized format needed to run on desktop computers, interact with the World Wide Web, and provide several levels of functionality.

The initial X3D effort was started in 1999 by the Web3D Consortium. X3D was the evolutionary successor to the Virtual Reality Modeling Language (VRML97). The X3D language was designed based on lessons learned from VRML97 achievements and many companies' early efforts.

OBJECTIVES

The purpose for developing the X3D standard was to 1) develop a royalty-free specification for broad 3D graphics functionality; 2) define multiple levels of functionality for implementation on various classes of hardware; 3) define a variety of data-encoding formats; and 4) maintain compatibility with predecessor technology as much as possible. These objectives were chosen so that the standard was understandable and usable, the resulting files fit into the larger Web architecture, and the content was displayable on a large range of displays. All of these objectives were met by X3D, which defined three equivalent encoding formats: an Extensible Markup Language (XML) version, a classic VRML version, and a compressed binary version. An X3D world (or X3D scene) was defined to be all the 3D content, animation behaviors, and user interaction needed for running an author-defined virtual environment.

ISSUING BODY AND SCHEDULE

Although standards development is often a slow process, a special relationship expedites the rapid yet thorough standardization process for X3D. All of the X3D standards are first developed by the X3D Working Group of the Web3D Consortium and then reviewed, approved, and issued by the International Organization for Standardization (ISO). Web3D is responsible for all aspects of X3D development, including market research, implementation and testing of features, and standards document development. Standards documents are then submitted to the ISO as committee draft text. Proposed revisions go through a series of reviews and approvals by national bodies to ensure completeness, correctness, and clarity.

The X3D specification is defined in three separate ISO documents. Each document consists of multiple parts for a current total of seven parts. Typically, there are updates for three or four of these parts undergoing the ISO review process at any given time. The first X3D specification document (ISO/IEC 19775-1) was approved by the ISO in 2004. The consortium submits amendments or revisions to the ISO every 12 to 18 months to keep current with advances in 3D graphics processing.

TARGET APPLICATIONS

X3D is designed for applications where 3D models and behaviors can best illustrate the spatial relationships and interactive features that are otherwise difficult to show. Example applications are legion and include the HSV Football Stadium in Germany (venue/event viewing), RayGun (social networking), Arabic language and cultural interaction (training), visual analysis of amino acids and proteins (scientific), subsea drilling rig simulation (maintenance and training), radiation therapy and surgical systems simulator (medical treatment), Earth atlas (education and scientific), Anti-Terrorism Force Protection for the U.S. Navy (mission planning), and eScene (emergency response).

STRUCTURE OF THE STANDARD

The three ISO documents comprising the X3D specification are "Abstract Functionality," "Encodings," and "Language Bindings." The first document (ISO/IEC-19775 Parts 1 and 2) defines the architecture and functionality of X3D. The second document (ISO/IEC-19776 Parts 1–3) defines three different encodings of the functionality. The third document (ISO/IEC-19777 Parts 1 and 2) defines the language-specific API bindings

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abstractly defined in ISO/IEC-19775-2. These documents are split into parts, each of which addresses a specific topic. Summarizing:

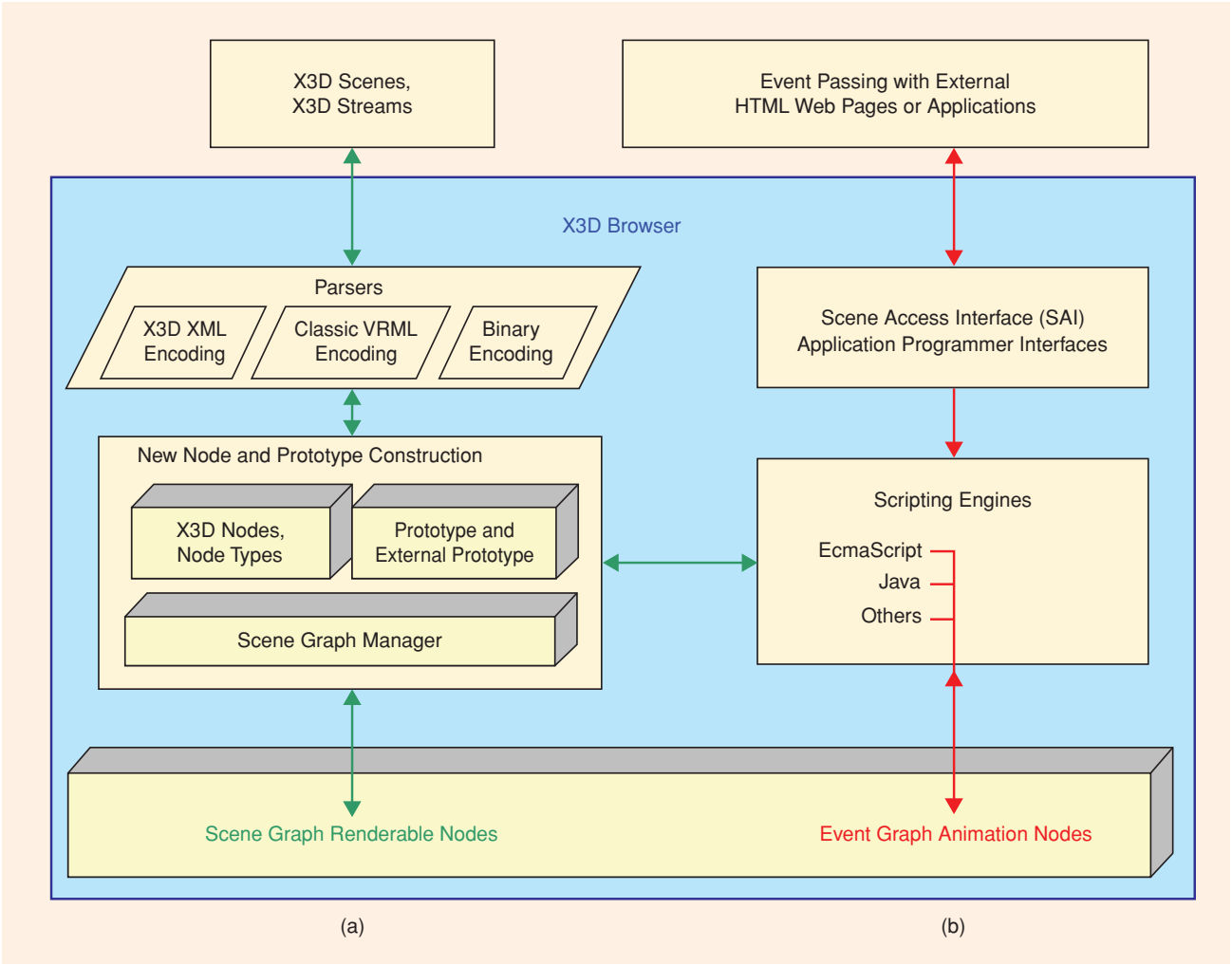
- *X3D Architecture and Base Components* defines the architecture and abstract definitions of all X3D components (ISO/IEC-19775-1).
- *X3D Scene Access Interface (SAI)* defines the abstract API to X3D (ISO/IEC-19775-2).
- *X3D Encodings: XML Encoding* defines the XML file encoding of an X3D world (ISO/IEC-19776-1).
- *X3D Encodings: Classic VRML Encoding* defines the classic VRML file encoding of an X3D world (ISO/IEC-19776-2).
- *X3D Encodings: Binary Encoding* defines the binary file encoding with optional compression (ISO/IEC-19776-3).
- *X3D Language Bindings: ECMAScript* defines the ECMAScript API to the SAI (ISO/IEC-19777-1).
- *X3D Language Bindings: Java* defines the Java API to the SAI (ISO/IEC-19777-2).

TECHNOLOGY

FUNCTIONALITIES

X3D provides a wide variety of capabilities used by the 3D community for rendering, texturing, modeling, animation, and user interactivity. Other advanced X3D components include geospatial positioning, interchangeable humanoid animation (H-Anim) bodies, and the IEEE Distributed Interactive Simulation (DIS) network protocol.

The rendering, texturing, and modeling functionalities are designed for consistent cross-platform interoperability, based on the functionalities provided by the low-level graphics-rendering engines OpenGL and DirectX. Such capabilities can also be implemented directly by a software renderer when such hardware-driven graphics acceleration is not available. Rendering and texturing features range from simple uniform coloring, color-per-face, color-per-vertex, and texture-image mapping to multiple-texture techniques and procedural shaders on an associated graphics processing unit.



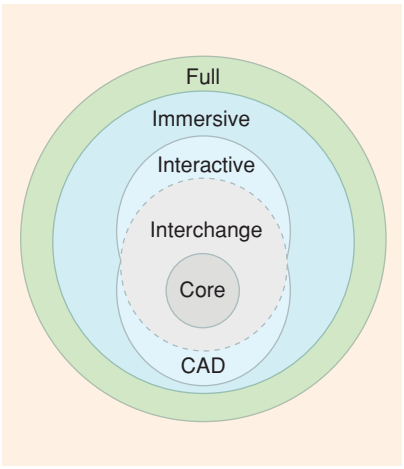
[FIG1] Example software architecture for an X3D browser with the main parts: (a) file parsing and rendering and (b) animation and dynamic scene-graph manipulation.

X3D geometric modeling capabilities range from low-level triangle-definition nodes (for the highest-possible performance) to geometric primitives (box, cone, cylinder, and sphere) and more advanced geometric nodes such as extrusion, elevationgrid, and nonuniform rational Bézier spline (NURBS) parametric surfaces.

X3D provides straightforward functionality for animation and interactivity. All of the animation nodes work by keyframe animation using linear interpolation. Complex animation sequences are efficiently constructed by linearly approximating the desired result. User-interactivity nodes capture events from standard interface devices (e.g., mouse and keyboard) and provide this data inside the X3D environment for processing by the browser's run-time engine.

Complex animation and user interaction can also be driven by software written in the ECMAScript (commonly known as JavaScript) or Java programming languages. The X3D specification requires support for ECMAScript within the X3D environment, whereas Java support is optional in order to keep Web-based implementations small and lightweight. Code within the X3D environment can use either X3D's event passing mechanism or the SAI mentioned earlier. Code external to the X3D environment may only use the SAI.

Further extensibility is provided within X3D itself through a prototyping mechanism. Authors can create prototype definitions of new nodes constructed from previously defined nodes and then re-instance them as needed.



[FIG2] X3D profiles are carefully nested to provide increasing functional sophistication. Note that the CADInterchange profile is labeled CAD in the diagram.

ARCHITECTURE

The example architecture of a sample X3D browser, illustrated in Figure 1, consists of file parsing and rendering [Figure 1(a)] and animation and dynamic scene graph manipulation [Figure 1(b)]. Browsers and applications that implement X3D capabilities are free to use any software architecture desired, as long as end results are visually and functionally correct.

X3D uses a hierarchical directed acyclic scene graph to define the location relationships and appearances of the 3D world. X3D also uses the run-time portion of the architecture to provide real-time animation and user-interaction capabilities, which greatly increase the "liveness" and perceived realism of the scene.

X3D scene files are encoded in XML, classic VRML, or compressed binary format. The XML encoding allows for self-validating X3D content that is Web-compatible and maximizes interoperability with other Web languages. The classic VRML encoding has the same structure as, and is backward compatible with, VRML97. The compressed binary encoding minimizes file size and maximizes parsing speed, allowing faster transmission and faster loading.

X3D scene graphs are typically defined as one or more files that are available to the browser locally or using Hypertext Transfer Protocol (HTTP). Each file is expressed in a single encoding, but different files may use different encodings and even refer to each other. These encodings are isomorphic to each other, allowing equivalent content functionality to exist in any of the three forms.

The X3D run-time architecture in Figure 1(b) includes the SAI and scripting engines. The SAI allows an application external to the X3D browser to perform operations inside the scene (everything from creating the environment and adding nodes to manipulating the environment) during run time. The SAI also governs the internal interface for direct manipulation of the environment by script code embedded in the X3D scene. X3D defines the SAI for ECMAScript and Java, with a structurally equivalent SAI binding for C++ likely to undergo future specification review. Browsers typically implement at least one of these languages.

X3D HARDWARE AND SOFTWARE PRODUCTS

Conformant Products (Interchange Profile, as of Autumn 2007)

- Xj3D (http://www.xj3d.org) from Yumetech, Inc. (http://yumetech.com)
- FreeWrl (http://freewrl.sourceforge.net) from Communications Research Centre, Canada (http://www.crc.ca)
- Flux Player from Media Machines (http://www.mediamachines.com)

Other Products

Software

- BS Contact VRML/X3D from Bitmanagement Software GmbH (http://www.bitmanagement.com)
- Flux Studio from Media Machines (http://www.mediamachines.com)
- Octaga Player, Octaga Professional, Octaga Exporter, and Octaga Panorama (http://www.octaga.com)
- WireFusion, Demicron Ltd. (http://www.demicron.com)

Hardware

- SensAble haptics through the use of H3D API (http://www.sensegraphics.com/products.php)
- H3D API also support SeeReal 3D monitors, DepthQ 3D projectors

TOOLS

A number of tools support the creation and display of X3D worlds. X3D-Edit is a free Java-based X3D/XML editor. It can also translate from XML to either classic VRML or VRML97 files using an extensible stylesheet language for transformations (XSLT) converter. Flux Studio is a WYSIWYG PC-based world building application. Other applications are listed in the "X3D Resources" section.

Common X3D browsers are BS Contact (Windows), Flux Studio (Windows), FreeWRL (Macintosh and Linux), Octaga Player (Windows), WireFusion (Java–Windows, Macintosh, and Linux), and the first X3D browser, Xj3D (Java–Windows, Macintosh, Linux, and Solaris). There are free-for-use download versions for all of these X3D browsers. FreeWRL, Flux Player, and Xj3D are open source.

PROFILES AND LEVELS

In general, a wide range of many different technical capabilities exist in 3D graphics. X3D strikes an effective balance between lightweight, efficient Web-based delivery and sophisticated computation-intensive applications by allowing authors to precisely define what capabilities are needed in each scene. Nodes with related functionality are collected into components. Most components are split into levels, where a level is a collection of nodes within the component that are similar in complexity. The 34 components provide hierarchical object-oriented interface definitions and specify the fundamental means for expressing X3D world functionality.

X3D defines each profile as a collection of components at specific levels. It is a shorthand mechanism for declaring the required functional sophistication of the X3D world. There are six defined profiles: four market-driven profiles ("Interchange," "CADInterchange," "Interactive," and "Immersive") and two definitional profiles ("Core" for minimal features, and "Full" for all features). The nesting relationship between the profiles is shown in Figure 2. The palette of capabilities provided in each profile is carefully scoped to allow both efficient

X3D RESOURCES

Tutorials

- L. Daly and D. Brutzman, "Advanced X3D graphics," in *SIGGRAPH 2003 Tutorial*, July 2003 [Online] Available: http://www.realism.com/x3d/tutorials
- C. Thorne and V. Weiley, "The next generation of virtual worlds with VRML, X3D and MPEG4," in *Proc. Graphite 2003 Int. Conf. Computer Graphics and Interactive Techniques in Australasia and South East Asia*, Melbourne, Australia, Feb. 2003.

Overviews

- X3D Help [Online]. Available: http://www.web3d.org/x3d/content/examples/help.html
- X3D Wiki [Online]. Available: http://www.web3d.org/x3d/wiki/index.php/Main_Page

Books and Articles

- D. Brutzman and L. Daly, *X3D: Extensible 3D Graphics for Web Authors.* Morgan-Kaufmann, 2007.
- V. Geroimenko and C. Chen, Eds., *Visualizing Information Using SVG and X3D.* New York: Springer, 2005.
- E. Dethe, "XML Matters: The Web ain't just for 2D any more," [Online]. Available: http://www-128.ibm.com/developerworks/web/library/x-matters43
- X3D Specifications [Online]. Available: http://www.web3d.org/x3d/specifications

Example Software

Browsers

- BS Contact VRML/X3D, and BS Contact Geo [Online]. Available: http://www.bitManagement.com
- Flux Player [Online]. Available: http://www.mediamachines.com
- FreeWRL [Online]. Available: http://freewrl.sourceforge.net
- Octaga [Online]. Available: http://www.octaga.com
- Xj3D [Online]. Available: http://www.xj3d.org

Content Creation Tools

- Flux Studio [Online]. Available: http://mediamachines.com
- H3D API: X3D Based Open Source Haptics and 3D Visualization API [Online]. Available: http://www.h3d.org
- Octaga Player and Modeller [Online]. Available: http://www.octaga.com
- SwirlX3D [Online]. Available: http://www.pinecoast.com/swirl3d.htm
- X3D-Edit [Online]. Available: http://www.web3d.org/x3d/content/README.X3D-Edit.html
- See more at the Tool Listing on Web3D [Online]. Available: http://www.web3d.org/tools

Applications

- RayGun and eScene [Online]. Available: http://www.planet9.com
- Case studies [Online]. Available: http://www.web3d.org/casestudies

Test Sequences

- Web3D Consortium Conformance Test Program [Online]. Available: http://www.web3d.org/x3d/conformance

Discussion List

- Unmoderated discussion list [Online]. Available: http://x3d-public@web3d.org

Other Related Resources

- Collada [Online]. Available: http://www.collada.org
- World Wide Web Consortium (W3C) [Online]. Available: http://www.w3c.org
- Open Geospatial Consortium (OGC) [Online]. Available: http://www.opengeospatial.org
- An expanded version of this resources list (http://www.realism.com/x3d/references)

software implementation and sensible content creation.

The Interchange profile is designed for the basic exchange of model geometry and texture-image content between various 3D content-creation applications. It includes simple animation interpolation but not user interaction. The CADInterchange profile adds geometric nodes and data structures to support the exchange of computer-aided design (CAD) data between different X3D-based applications. It maintains the hierarchical piece/part structure as normally defined in common CAD models. The Interactive profile adds user interaction, network protocols, and additional lighting. The Immersive profile is designed to provide all of the necessary functionality to develop a desktop-based immersive environment. It is the most commonly used profile. The Core profile defines only the basic functionality of X3D. It has no displayable nodes and is useful only as a base for adding individual components to build highly optimized and specialized worlds. The Full profile includes all X3D functionality. Although no browser yet supports the entire Full profile, some are nearly complete. Because multiple implementations (including at least one open-source implementation) must demonstrate interoperability before new component technologies can be included in the X3D standard, multiple browsers support each of the many X3D components.

COMPARISON WITH OTHER STANDARDS

X3D is the only open standard available that provides thorough support for real-time, interactive animation and rendering of 3D graphics. Formal development of the VRML standard, which is the predecessor of X3D, was completed with the release of X3D.

Other related formats include Universal 3D (U3D), OpenInventor, Coin3D, and Collada. U3D is designed for repurposing and visualization of CAD models and provides for geometry, continuous level of detail, data streaming, and animation. U3D does not support interactivity and specifically does not address rendering of 3D content. OpenInventor was the primary predecessor of VRML. It is not active, but Coin3D fully supports OpenInventor 3D. Coin3D is designed more for local applications rather than Web-based and Web-aware applications. Collada is maintained by the Khronos Group as an open digital asset exchange and archive format. Neither Coin3D nor Collada has been approved by an independent standards organization.

Complementary relationships between X3D and other formats are likely to continue to grow, since X3D is designed as a broadly capable format that is easily imported and exported while remaining suitably stable for long-term archival purposes.

PERFORMANCE

CONFORMANCE

The Web3D Consortium runs a conformance program that issues an "X3D conformant" seal to software or hardware products that pass the conformance test. The test suite is initially self-administered by implementing company members, and test results are formally verified by the Web3D Consortium. The individual tests check functional conformance to the standard for a particular profile (now available for the Interactive profile). The conformance program is being expanded and implemented for the other profiles. Browsers may choose to support any combination of profiles, but Core is always required. Therefore, the Core profile conformance test suite is also built into the conformance test suites for the other profiles.

The Web3D Consortium's conformance program is designed to promote consistent and reliable implementations of the X3D standard across multiple platforms. Browsers seeking to claim X3D conformance must at least meet the functionality as specified for that conformance profile.

SPEED

The run-time processing performance of an X3D browser is controlled by the time required to render each individual screen display, i.e., each frame. Scene complexity is carefully structured and optimized to maximize rendering frame rate. X3D provides author-controlled mechanisms (such as subtree switching or level-of-detail proximity checks) that can remove unneeded elements from the rendering cycle to improve performance. Current personal computer systems with graphics-hardware acceleration are able to render all but the most complex scenes at visually smooth rates (15 frames/s or faster). However, neither the X3D standard nor the conformance test suite specifies a minimum or maximum frame rate, since the scope of X3D capabilities and variations in both implementations and delivery platforms can vary so widely. There is no requirement for graphical hardware acceleration; however, the frame rate may be significantly slower on systems without it. In any case, animations must proceed at the proper real-time speed regardless of frame rate, guaranteeing a consistent end-user experience.

FURTHER TECHNICAL DEVELOPMENTS

The X3D specification is designed to be both flexible and extensible, and so it continues to be revised and amended. Such additions can support new functionality as it is introduced and deployed by the 3D hardware industry. Current X3D efforts include adding superior binary compression, improved navigation features, geospatial visualization as part of X3D Earth, and network protocols for distributing the X3D event model. The Web3D Consortium has member policies and working practices in place to help ensure that no undeclared proprietary intellectual property is included in the specifications. Patented technology may be adopted, but only under royalty-free terms, in order to ensure the widest possible Web use.

X3D is designed to work compatibly within the context of the World Wide Web and thus needs to interoperate with other XML-based specifications, applications, and file formats. To this

end, the Web3D Consortium is actively engaged with several external organizations to ensure interoperability and compatibility with other standards (the World Wide Web Consortium and Open Geospatial Consortium) and to develop best-practice conversions (Khronos Group for Collada). It continues to improve X3D, providing important new business opportunities and further extending the Web.

X3D technical development continues to be innovative and exciting. Companies, institutions, and individuals can all take advantage of X3D's many capabilities and steady growth. Each is also welcome to join the Web3D Consortium to further advance the X3D graphics standard.

RESOURCES

Tutorials, overviews, books, links to available software, and other resources are included in the "X3D Resources" sidebar. An expanded version of the resources list is also available following a link provided in "X3D Resources."

PRODUCTS

Information on software and hardware products using X3D is available in "X3D Hardware and Software Products."

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Both are coauthors of the book *X3D: Extensible 3D Graphics for Web Authors* (www.x3dGraphics).