

X3D Ontology for Semantic Web

Visioning Lab: Metaverse Ontology Workshop

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VISIONING LAB

Motivational stance

- Standards Register working group in Metaverse Standards Forum (MSF) is performing key activities needed for achieving scalable interoperability: vocabularies, use cases
- 3D Web Interoperability working group is building a possible path to expose and interconnect diverse metaverse assets
- X3D Graphics International Standard is common ground for adapting all manner of interactive 3D graphics on Web (via conversions or native loading) as a large scene graph
- X3D Ontology provides representations for graphics and metadata for direct query useful to higher-level constructs
- **Ontology composition for metaverse** offers potential for new capabilities in query, search, reasoning and connection



Semantic Web

- W3C is helping to build a technology stack to support a “Web of data” supported by Semantic Web standards.
- Wikipedia: “The **Semantic Web** is an extension of the World Wide Web through standards set by the World Wide Web Consortium (W3C). The goal of the Semantic Web is to make Internet data machine-readable. To enable the encoding of semantics with the data, technologies such as Resource Description Framework (RDF) and Web Ontology Language (OWL) are used. These technologies are used to formally represent metadata. For example, ontology can describe concepts, relationships between entities, and categories of things. These embedded semantics offer significant advantages such as reasoning over data and operating with heterogeneous data sources.”



X3D Ontology for Semantic Web

The X3D Ontology for Semantic Web provides terms of reference for semantic query of X3D models.

[Motivation](#) | [Availability](#) | [Design](#) and [Design Patterns](#) | [OWLDoc](#) | [Queries](#) | [References](#) | [Tools](#) | [TODO](#) | [Contact](#)

Motivation



The [X3D Semantic Web Working Group](#) mission is to publish models to the Web using X3D in order to best gain Web interoperability and enable intelligent 3D applications, feature-based 3D model querying, and reasoning over 3D scenes.

Motivating insights:

"The answer to your question is the response to the query." Jim Hendler and Dean Allemang

"Trying to use the Semantic Web without SPARQL is like trying to use a relational database without SQL." Tim Berners-Lee

["The proof of the pudding is in the eating."](#) Wiktionary

<https://www.web3d.org/x3d/content/semantics>

What is the X3D Ontology?

- A thorough representation of X3D Architecture using RDF and OWL.
 - **RDF:** [Resource Description Framework](#)
 - **OWL:** [Web Ontology Language](#)
 - Expressed in **Turtle** form, the [Terse Triple Language \(.ttl\)](#)
- A strictly typed definition of all X3D nodes, fields and data types.
- A way to “explode” an X3D model into subject-predicate-object triples.
- Basis for model search and query reasoning when
 - Example X3D scene is also converted into .ttl form
 - Queries are written in **SPARQL**, the [SPARQL Protocol and RDF Query Language](#)
- Experimental, but design examples are converging satisfactorily.

What is the X3D Ontology *not*?

- X3D Ontology is not suitable for 3D scene graph rendering in real time.
- X3D Ontology is not suitable for programmatic creation of 3D models.
- ... thus not suitable for most tasks familiar to 3D graphics modelers.

Not a problem. The triple form of an X3D model is instead optimized for search queries and logical inference, using Semantic Web technologies.

OBTW current activity includes the possibility of round-trip conversion, but only as a way to confirm complete mappings of all model information. Equivalent information models are possible, but for different purposes. Such a capability is optional, primary production is X3D model to triples.

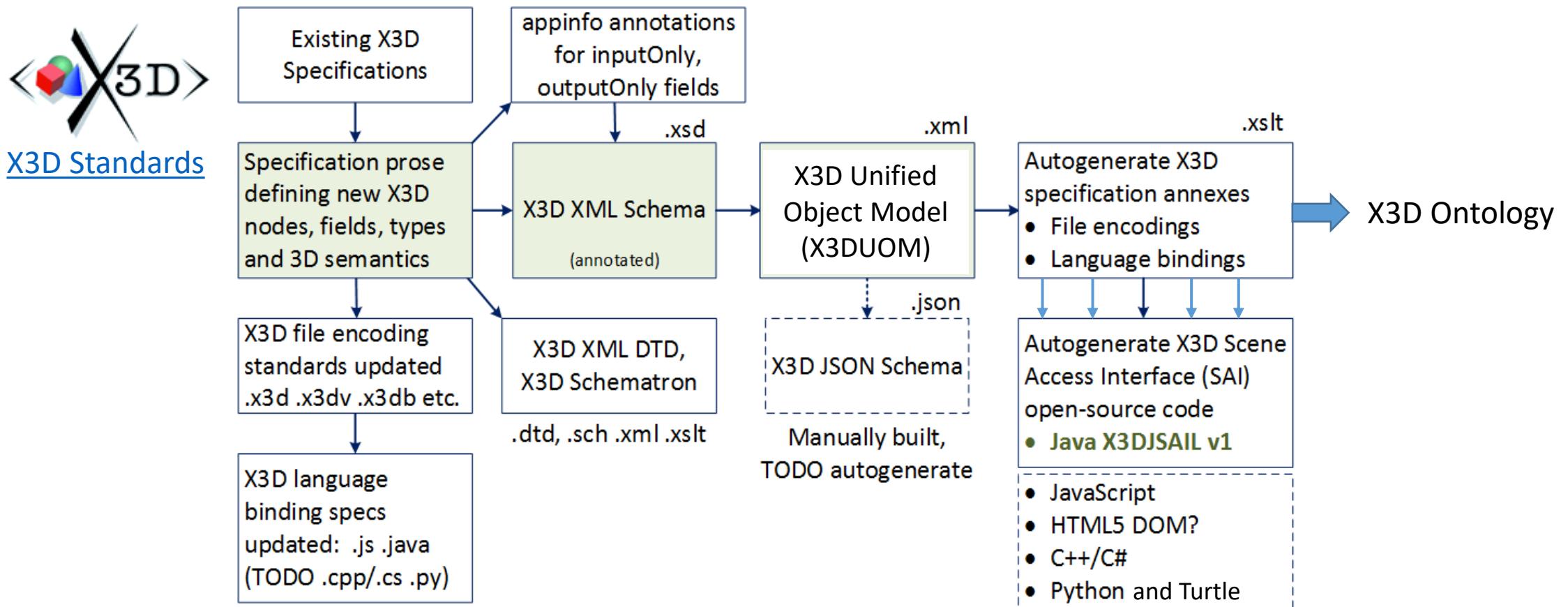
Assets available for X3D Ontology testing

- [X3dOntology4.0.ttl](#) is primary work, described in [Web3D 2020 paper](#).
- [OWLDoc documentation](#) is generated via [Protégé](#) ontology editor.
- [X3dToTurtle.xslt](#) conversion stylesheet for converting any .x3d model from XML into .ttl triples.
- [X3dSemanticWebDevelopmentArchive.zip](#) collects current assets for easier download and use.
- Build process: [build.xml](#) uses [Apache Ant](#) and [Apache Jena ARQ](#) with output logs: [build.all.log.txt](#) and [build.SPARQL.query.tests.log.txt](#)

This Web3D work is [Open Source](#) and maintained in [version control](#).

Production Chain for Creation of X3D Ontology

Creation of the X3D Ontology is thorough and autogenerated for each version of X3D, based on [**X3D Unified Object Model \(X3DUOM\)**](#)





Project

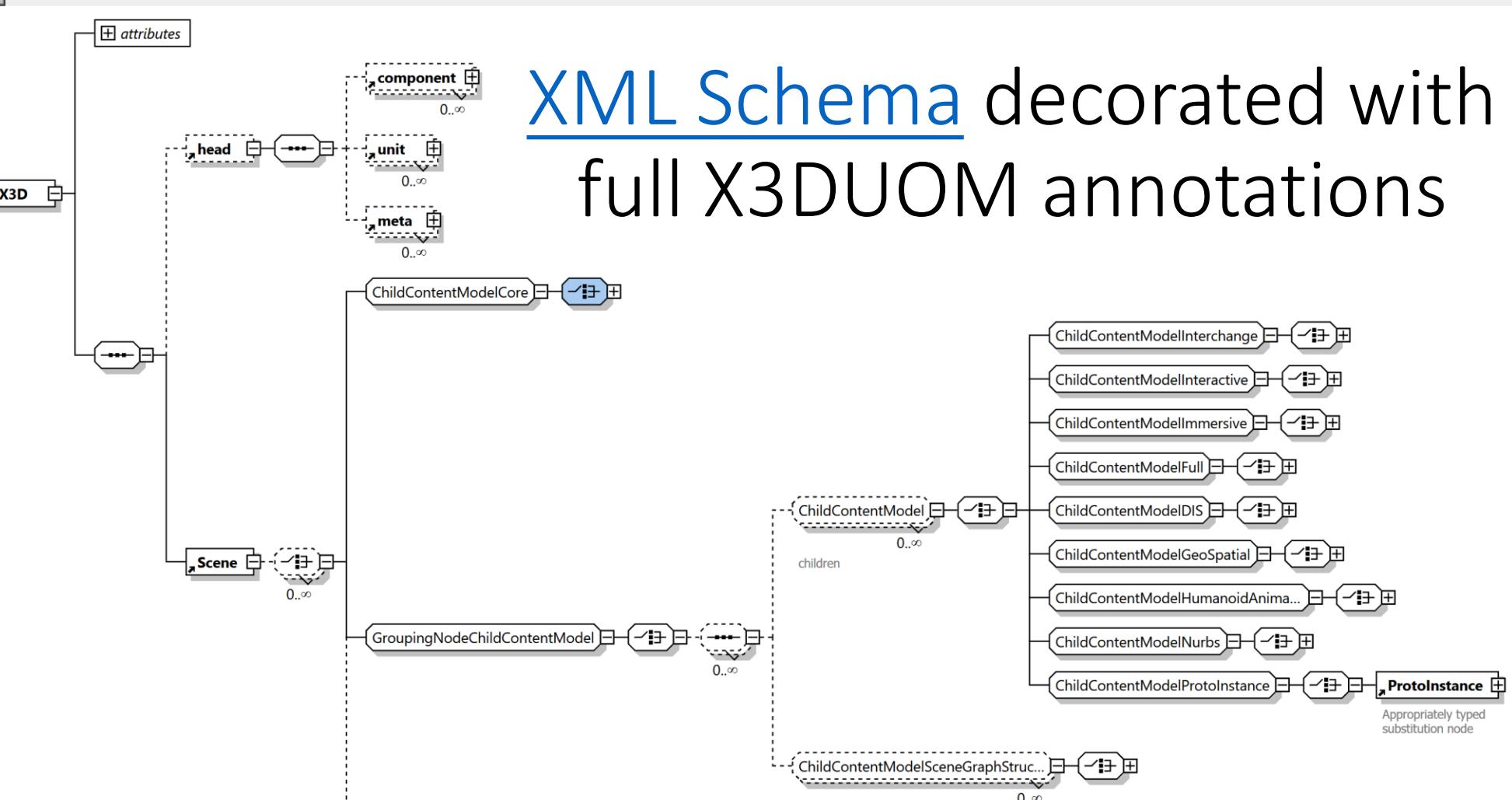
X3dSchemaDtd-XmlSpyProject

- DTD extensions
- Schema extensions
- Stylesheets
- X3D Schematron
- Test scenes
- KML
- X3D Unified Object Model (X3DUOM)
- X3D Java SAI Library X3DJSAIL
- X3D JSON Schema
- DTD** x3d-3.0.dtd
- XSD** x3d-3.0.xsd
- DTD** x3d-3.1.dtd
- XSD** x3d-3.1.xsd
- DTD** x3d-3.2.dtd
- XSD** x3d-3.2.xsd
- DTD** x3d-3.3.dtd
- XSD** x3d-3.3.xsd
- DTD** x3d-4.0.dtd
- XSD** x3d-4.0.xsd
- x3d-dtd-changelog.txt
- x3d-schema-changelog.txt

Info

- Enable Extended Schema Validation

No Schema Rule files assigned



Text Grid Schema WSDL XBRL Authentic Browser

x3d-4.0.xsd x3d-4.0.dtd

Messages



File C:\x3d-code\www.web3d.org\specifications\x3d-4.0.dtd is valid.

X3DUOM in Netbeans

```

<?xml version="1.0" encoding="UTF-8"?>
<!-- X3D Unified Object Model (X3DUOM) X3dUnifiedObjectModel-4.0.xml -->
<!-- Online at https://www.web3d.org/specifications/X3dUnifiedObjectModel-4.0.xml -->
<!-- This file contains a listing of all abstract and concrete nodes in version 4.0 of X3D -->
<!-- Generated 2019-07-21T07:00 05:37:06.669802-07:00 -->
<X3dUnifiedObjectModel xmlns:xsd="http://www.w3.org/2001/XMLSchema-instance"
version="4.0"
xsd:noNamespaceSchemaLocation="X3dUnifiedObjectModel.xsd">
  <SimpleTypeEnumerations>
  <FieldTypes>
  <AbstractObjectTypes>
  <AbstractNodeTypes>
  <ConcreteNodes>
  <Statements>
</X3dUnifiedObjectModel>

```

Find: class X3D

Output... X Versioning Output Notifications Search Results Terminal - .../e/c/Program Files/NetBeans_11.0/bin Git - [NetworkedGraphicsMV3500] - master

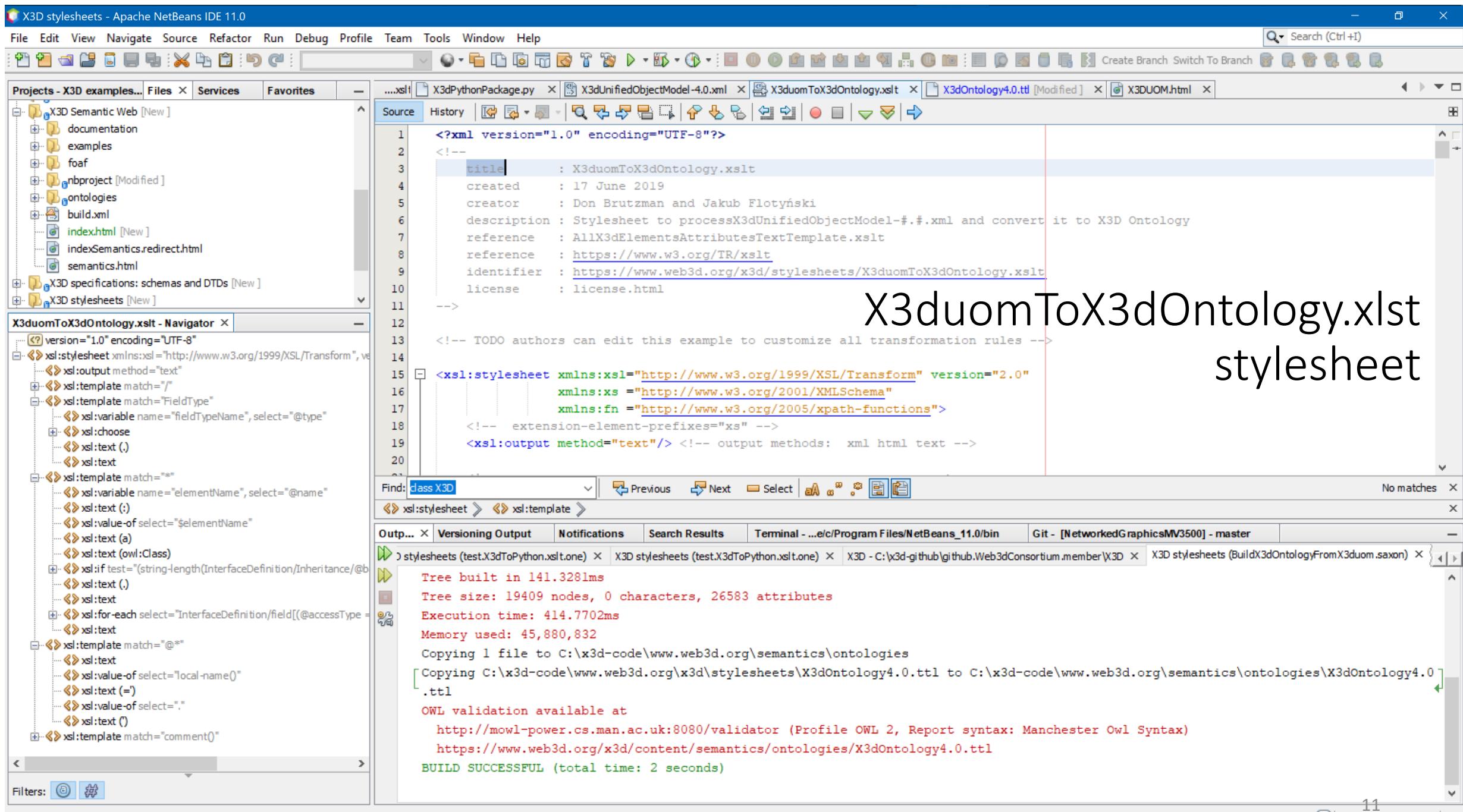
Stylesheets (test.X3dToPython.xslt.one) X3D stylesheets (test.X3dToPython.xslt.one) X3D - C:\x3d-github\github.Web3dConsortium.member\X3D X3D stylesheets (BuildX3dOntologyFromX3duom.saxon)

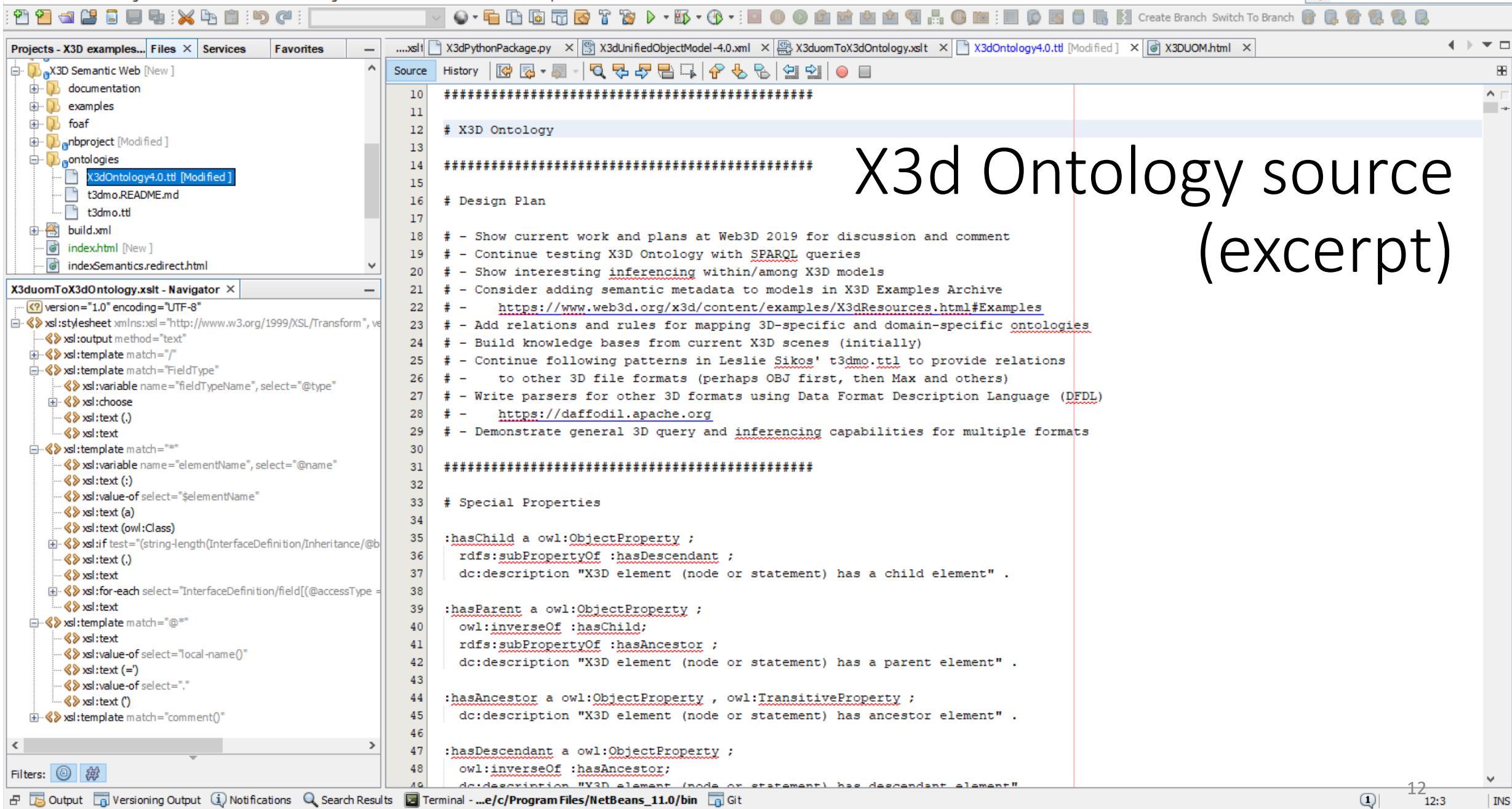
```

Tree built in 141.3281ms
Tree size: 19409 nodes, 0 characters, 26583 attributes
Execution time: 414.7702ms
Memory used: 45,880,832
Copying 1 file to C:\x3d-code\www.web3d.org\semantics\ontologies
Copying C:\x3d-code\www.web3d.org\x3d\stylesheets\X3dOntology4.0.ttl to C:\x3d-code\www.web3d.org\semantics\ontologies\X3dOntology4.0.ttl
OWL validation available at
  http://mowl-power.cs.man.ac.uk:8080/validator (Profile OWL 2, Report syntax: Manchester Owl Syntax)
  https://www.web3d.org/x3d/content/semantics/ontologies/X3dOntology4.0.ttl
BUILD SUCCESSFUL (total time: 2 seconds)

```

Filters: #





X3d Ontology source (excerpt)

X3D Ontology excerpt

```
:WorldInfo a owl:Class ;
  rdfs:subClassOf :X3DInfoNode ;
  rdfs:label "WorldInfo contains a title and simple persistent metadata information about an X3D scene. This node is strictly for documentation purposes and has no effect on the visual appearance or behaviour of the world." .

:info a owl:DatatypeProperty ;
  rdfs:domain :WorldInfo ;
  rdfs:range :MFString .

:title a owl:DatatypeProperty ;
  rdfs:domain :WorldInfo ;
  rdfs:range :SFString .

# DEF field inheritedFrom=X3DNode with accessType=inputOutput, type=SFString, baseType=xs:ID
# USE field inheritedFrom=X3DNode with accessType=inputOutput, type=SFString, baseType=xs:IDREF
# class field inheritedFrom=X3DNode with accessType=inputOutput, type=SFString,
baseType=xs:NMTOKENS
# IS field inheritedFrom=X3DNode with accessType=inputOutput, type=SFNode, default=NULL
# metadata field inheritedFrom=X3DNode with accessType=inputOutput, type=SFNode, default=NULL
```

Full set of data typing and scene graph parent-child relationships available.

Enables precise query of any X3D model.



- owl:Thing
 - component
 - connect
 - EXPORT
 - ExternProtoDeclare
 - field
 - fieldValue
 - head
 - IMPORT
 - IS
 - meta
 - ProtoBody
 - ProtoDeclare
 - ProtolInterface
 - ROUTE
 - Scene
 - unit
 - X3D
 - X3DBoundedObject
 - X3DFogObject
 - X3DMetadataObject
 - X3DNode
 - CollisionCollection
 - Contact
 - Contour2D
 - GeoOrigin
 - LayerSet



- X3DBoundedObject
- X3DFogObject
- X3DMetadataObject
- X3DNode
 - X3DPickableObject
 - X3DProgrammableShaderObject
 - X3DUrlObject

X3D Ontology in Protégé

Search...

Usage: X3DNode

Show: this disjoint named sub/superclasses

Found 66 uses of X3DNode

- class
 - class Domain X3DNode
- CollisionCollection
 - CollisionCollection SubClassOf X3DNode
- Contact
 - Contact SubClassOf X3DNode
- Contour2D
 - Contour2D SubClassOf X3DNode
- DEF
 - DEF Domain X3DNode
- GeoOrigin
 - GeoOrigin SubClassOf X3DNode
- hasChildren
 - hasChildren Range X3DNode

Description: X3DNode

Equivalent To [+](#)SubClass Of [+](#)General class axioms [+](#)

SubClass Of (Anonymous Ancestor)



Ontology metrics:

Metrics

| | |
|---------------------------|------|
| Axiom | 3711 |
| Logical axiom count | 2543 |
| Declaration axioms count | 1124 |
| Class count | 320 |
| Object property count | 376 |
| Data property count | 488 |
| Individual count | 3 |
| Annotation Property count | 1 |

Class axioms

| | |
|-------------------|-----|
| SubClassOf | 296 |
| EquivalentClasses | 0 |
| DisjointClasses | 0 |
| GCI count | 0 |
| Hidden GCI Count | 0 |

Object property axioms

| | |
|---------------------------------|-----|
| SubObjectPropertyOf | 283 |
| EquivalentObjectProperties | 0 |
| InverseObjectProperties | 174 |
| DisjointObjectProperties | 0 |
| FunctionalObjectProperty | 0 |
| InverseFunctionalObjectProperty | 0 |
| TransitiveObjectProperty | 1 |
| SymmetricObjectProperty | 0 |
| AsymmetricObjectProperty | 0 |
| ReflexiveObjectProperty | 0 |
| IrreflexiveObjectProperty | 0 |
| ObjectPropertyDomain | 184 |
| ObjectPropertyRange | 111 |
| SubPropertyChainOf | 0 |

Data property axioms

Synchronising

X3D model representation in Turtle .ttl form

- Goal: broadly apply X3D Ontology to enable precise, in-depth SPARQL queries
- Unique naming pattern is necessary for each X3D node in a model:
 - DEF names, if available, are prefixed by a colon. Example is **:MySpecialMaterial**.
 - USE names, if available, are adapted by prefixing with a colon and appending -USE- and the number of current occurrence. Example is **:MySpecialMaterial-USE-4**.
 - X3D, head and Scene are always singletons and so are eponymous and always get the same name, e.g. **:X3D**, **:head** and **:Scene**.
 - Unnamed X3D nodes and statements are identified with the following pattern: node name, followed by tree hierarchy below the root X3D node.
 - Example labels: **:meta_1_5** has 1 for head and 5 for fifth child; **:Shape_2_3_2_1** has initial 2 for Scene followed by second/second/first children nodes, and so on
- Automated conversion .x3d to .ttl using [X3dToTurtle.xslt](#) stylesheet
- Convert all models and metadata in [X3D Examples Archives](#) for testing!

Full set of examples

- Several thousand XML-based .x3d models in the [X3D Example Archives](#) have been converted into .ttl Turtle triples, using the [X3dToTurtle.xslt](#) conversion stylesheet.
- Both .ttl and SPARQL query results are available for each model, as illustrated in the screenshot for the HelloWorld example catalog entry.
- Comprehensive conversion and test-query results for all models in X3D Resources, Examples: Scene Archives for X3D are listed in [build.turtle.all.log.txt](#). This is a comprehensive set of unit tests for X3D ontology, .xslt conversion of 3D models into .ttl, and SPARQL query.

Example model in X3D Examples Archive: Hello World

link to [X3D model](#)

X3D Example Archives: X3D4WA, X3D for Web Authors, Chapter 01 Technical Overview, Hello World

Simple X3D model example: Hello World!



X3D model source .x3d

X ITE (Playground)

X3DOM (X3DOM editor)

ClassicVRML .x3dv

.java source (Javadoc)

VRML97 .json (check)

Canonical XML .py python

X3D Model Documentation

x3db Compressed Binary Encoding

Version control

Trouble tickets

Email x3d-public

X3D Model Documentation: HelloWorld.x3d

link to [RDF-OWL](#) and [SPARQL query](#)

```
1 <?xml version="1.0" encoding="UTF-8"?>
2 <!DOCTYPE X3D PUBLIC "ISO//Web3D//DTD X3D 3.3//EN" "https://www.web3d.org/specifications/x3d-3.3.dtd">
3 <X3D profile='Immersive' version='3.3' xmlns:xsd='http://www.w3.org/2001/XMLSchema-instance' xsd:noNamespaceSchemaLocation='https://www.web3d.org/specifications/x3d-3.3.xsd'>
4   <head>
5     <!-- Alternate encodings: VRML97, X3D ClassicVRML Encoding, X3D Compressed Binary Encoding (CBE), X3DOM, JSON -->
6     <meta name='title' content='HelloWorld.x3d' />
7     <meta name='description' content='Simple X3D model example: Hello World!' />
8     <meta name='created' content='30 October 2000' />
9     <meta name='modified' content='9 July 2023' />
10    <meta name='creator' content='Don Brutzman' />
11    <meta name='Image' content='HelloWorld.tall.png' />
12    <meta name='reference' content='https://en.wikipedia.org/wiki/Hello_world' />
13    <meta name='reference' content='https://en.wikipedia.org/wiki/Hello#.22Hello.2C_World.22_computer_program' />
```

Example excerpt, [HelloWorld.ttl](#) (converted from [HelloWorld.x3d](#))

```
:Shape_2_3_2_1 a owl:NamedIndividual, x3do:Shape ;
  x3do:hasParent :TestWhitespaceCommas ;
  x3do:hasGeometry :Sphere_2_3_2_1_1 ;
  x3do:hasAppearance :Appearance_2_3_2_1_2 .

:Sphere_2_3_2_1_1 a owl:NamedIndividual, x3do:Sphere ;
  x3do:hasParent :Shape_2_3_2_1 .

:Appearance_2_3_2_1_2 a owl:NamedIndividual, x3do:Appearance ;
  x3do:hasParent :Shape_2_3_2_1 ;
  x3do:hasMaterial :MaterialLightBlue ;
  x3do:hasTexture :ImageCloudlessEarth .

:MaterialLightBlue a owl:NamedIndividual, x3do:Material ;
  x3do:hasParent :Appearance_2_3_2_1_2 ;
  x3do:diffuseColor ( 0.1 0.5 1 ) .

:ImageCloudlessEarth a owl:NamedIndividual, x3do:ImageTexture ;
  x3do:hasParent :Appearance_2_3_2_1_2 ;
  x3do:url '"earth-topo.png" "earth-topo.jpg" "earth-topo-small.gif" ' .
```

SPARQL Query: X3dHelloWorldQuery_03.rq

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX x3d: <http://www.web3d.org/specifications/x3d-4.0.xsd#>
PREFIX x3do: <http://www.web3d.org/semantics/ontologies/X3dOntology4.0#>

# X3dHelloWorldQuery_03.rq      Query HelloWorld.ttl to show title given to model within a WorldInfo node.

#####
# SELECT ?WorldInfoNode ?title ?parentNode
# WHERE
# {
#   ?WorldInfo rdf:type x3do:WorldInfo ;
#               x3do:title ?title ;
#               x3do:hasParent ?parent .
#
#   BIND (strafter(xsd:string(?WorldInfo), "#") AS ?WorldInfoNode)
#   BIND (strafter(xsd:string(?parent), "#") AS ?parentNode)
# }

#####
```

Query response: [X3dHelloWorldQuery 03.rq.txt](#)

```
#####
SELECT ?WorldInfoNode ?title ?parentNode
WHERE
{
    ?WorldInfo rdf:type          x3do:WorldInfo ;
                x3do:title      ?title          ;
                x3do:hasParent  ?parent .
    BIND (strafter(xsd:string(?WorldInfo), "#") AS ?WorldInfoNode)
    BIND (strafter(xsd:string(?parent), "#")  AS ?parentNode)
}
#####
```

```
-----  
| WorldInfoNode | title          | parentNode |  
=====  
| "WorldInfo_2_1" | "Hello World!" | "Scene"   |  
-----
```

SPARQL
query

Simple
results

Asking, answering more-difficult 3D questions

Quality Assurance (QA) of sophisticated behavior is challenging. Can we query?

- Example: do connections exist for intended user interactions, model animation?
- Can we automate such error-detection queries for massive X3D model archives?

| parentNode | RouteFound | fromNodeDEF | fromNodeTypeFound | fromField | toNodeDEF | toField |
|-------------------------|---------------|---------------------------|------------------------------|--------------------|-------------------------|----------------|
| "Scene" | "ROUTE_2_5" | "OrbitalTimeInterval" | x3do:TimeSensor | "fraction_changed" | "SpinThoseThings" | "set_fraction" |
| "EarthCoordinateSystem" | "ROUTE_2_6_1" | "SpinThoseThings" | x3do:OrientationInterpolator | "value_changed" | "EarthCoordinateSystem" | "set_rotation" |
| "EarthCoordinateSystem" | "ROUTE_2_6_5" | "ClickTriggerTouchSensor" | x3do:TouchSensor | "touchTime" | "OrbitalTimeInterval" | "startTime" |

- Complementary compatible domains are possible: **3D printing** and **3D scanning**
- Future queries: document metadata, embedded-in-model metadata, topology and geometric structure, size and shape relationships, intended purpose, etc.
- Future horizon: Hybrid queries across linked models in multiple 3D formats

Future Work Opportunities

- Many more SPARQL queries! *If we can precisely state it, we can search for it...*
 - Current: query to check all animation chains (source/ROUTE/destination nodes)
- Capturing vocabularies, mapping metadata descriptions within X3D models
- Consider various ontologies for geometry, building information models (BIM)
- Simple projects to establish design patterns and good practices
- Investigate existing vocabularies and tools for [visual 3D shape search](#) including potential analysis and annotation of models. Can we align?
- Define similar/corresponding triple constructs for different 3D formats, building upon design patterns in Leslie Sikos' [t3dmo.ttl](#) exemplars.
- Experiment with [Data Format Description Language \(DFDL\)](#) 2-way mappings using [Apache Daffodil](#), and perhaps [RDF Mapping Language \(RML\)](#), as mechanisms to adaptively parse and subsequently perform queries on various other 3D formats coherently and comprehensively.

X3D Semantic Web Working Group

- The [X3D Semantic Web Working Group](#) mission is to publish models to the Web using X3D in order to best gain Web interoperability and enable intelligent 3D applications, feature-based 3D model querying, and reasoning over 3D scenes.

Motivations

- Establish best practices for metadata and semantic information/relationships using X3D as a Web-based presentation layer.
- Enable authors to utilize the power of X3Dv4 and HTML5/DOM together in any Web page utilizing a family of specifications and practices provided by the Semantic Web, such as HTML5 Microdata (microformats) and Linked Open Data, MPEG-7 and related references.
- Align the X3Dv4 specification with these standards as best possible to further enable the Digital Publishing industry and communities.
- Describe value proposition for utilizing semantic information in concert with archival export, publishing, visualization, and printing of any 3D model as X3D.

X3D Semantic Web Working Group

2

Goals

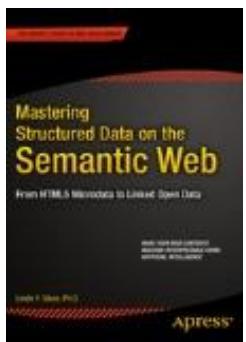
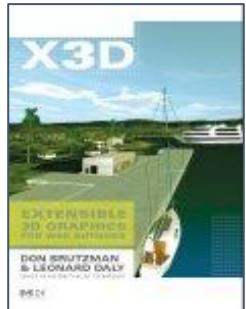
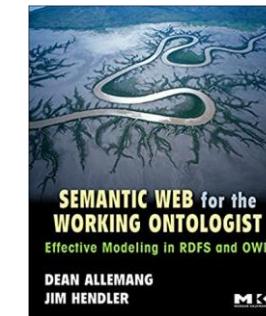
- Enable more effective indexing, search, comparison, and analysis of X3D models through the advanced use of metadata, shape geometry, etc.
- Create, autogenerate X3Dv4 OWL ontology from X3D Unified Object Model (X3DUOM) using best-practice design patterns, starting with those shown by prior published work.
- Support various Web3D Working Groups including Computer-Aided Design (CAD), 3D printing/scanning, Medical, Cultural and Natural Heritage, Humanoid Animation (HAnim) design work may consider other potential domains such as Building Information Models (BIM), etc.
- Build list of domain-specific controlled vocabularies and taxonomies suitable for use with X3D Ontology.
- Maximize interoperability with Semantic Web standards for greatest possible reuse, integration with Web.

Outcomes

- Create appropriate specifications and recommended practices.
- Build suite of exemplars and tools exposed through various portals.
- Publish [X3D Ontology](#) in multiple formats: [Terse RDF Triple Language \(Turtle\)](#), [RDF/OWL](#), (TODO) [JSON-LD](#).

Recommended Reading: Semantic Web, X3D

- Dean Allemang and Jim Hendler, [Semantic Web for the Working Ontologist: Effective Modeling in RDFS and OWL](#), second edition, 2012.
- Don Brutzman and Leonard Daly, [X3D for Web Authors](#), Morgan, 2007.
- Bob DuCharme, [Learning SPARQL](#), second edition, 2013.
- Leslie F. Sikos, [Mastering Structured Data on the Semantic Web: from HTML5 Microdata to Linked Open Data](#), 2015.
- Wikibooks [SPARQL](#) edition covers both language and also Web-based GUI: Wikidata Query Service SPARQL endpoint.



Contact

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[X3D Standards Working Group](#)

[Web3D Consortium](#)

Questions, insights and feedback are always welcome.

Have fun with X3D!

