Describing Semantics of 3D Web Content with RDFa

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***Abstract*—The paper presents a method of describing semantics of 3D web content with RDFa—Resource Description Framework in Attributes. Dependencies between 3D web components are typically more complex than dependencies between standard web pages as they may relate to different aspects of the 3D content—spatial, temporal, structural, logical and behavioural. Semantic Web standards help in making data understandable and processable for both humans and computers. RDFa is an RDF-compliant standard designed for creating semantic descriptions embedded into web resources, but it has been indented mostly for 2D web pages and not for 3D web content. The main contribution of this paper is a method of creating lightweight attribute-based built-in semantic descriptions of X3D web content. The method utilizes the standard syntax and structure of X3D documents providing a mapping of RDFa attributes to metadata nodes in 3D models. Due to the use of the standardized solutions, the proposed method enables flexible semantic descriptions of content for use in a variety of 3D applications on the web.**

***Index Terms*—3D content, semantic description, X3D, RDFa, 3D web.**

I. Introduction

Interactive 3D technologies enable significant progress in the quality and functionality of human-computer interfaces. The widespread use of interactive 3D technologies, including virtual reality (VR) and augmented reality (AR), has been recently enabled by significant progress in computing hardware performance, increasing availability of versatile input-output devices as well as rapid growth in the available network bandwidth. However, the potential of 3D/VR/AR technologies in everyday applications can be fully exploited only if accompanied by the development of efficient and easy-to-use methods of creation, publication and sharing of interactive 3D multimedia content.

Building, searching and combining distributed three-dimensional interactive content is a much more complex and challenging task than in the case of standard web pages. The relationships between components of an interactive three-dimensional virtual scene may include, in addition to its basic meaning and presentation form, spatial, temporal, structural, logical, and behavioural aspects.

Opportunities for widespread dissemination of 3D content may be significantly increased by applying the Semantic Web approach. Research on the Semantic Web has been initiated by T. Berners-Lee and the W3C (World-Wide Web Consortium) in 2001. This research aims at evolutionary development of the current web towards a distributed semantic database, linking structured content and documents. Semantic description of web content makes it understandable for both humans and computers, achieving a new quality in building web applications that can "understand" the meaning of particular components of content and services, as well as their relationships, leading to much better methods of searching, reasoning, combining and presenting web content.

The Resource Description Framework (RDF) [1] has been developed as the foundation of the Semantic Web, enabling semantic descriptions of various types of web resources. The Resource Description Framework in Attributes (RDFa) [2] is an RDF-compliant solution designed for creating lightweight semantic descriptions of web content with attributes built into described documents.

To enable 3D content description on the web, a number of proprietary data formats have been devised. In contrast to them, the Virtual Reality Modelling Language (VRML) [3] and its successor—the Extensible 3D (X3D) [4] have been developed by the Web3D Consortium as open standards. The openness determines the common use of X3D in a variety of applications, as well as attempts to combine it with other open standards, in particular for the Semantic Web. Currently, X3D provides basic mechanisms for including metadata into 3D models, but it does not standardize creation of semantic descriptions of resources. In turn, RDFa is intended mostly for 2D web pages and not for 3D web content. Embedding semantics directly into 3D content has several important advantages in comparison to decoupling semantics from 3D models. In particular, this enables more concise semantic descriptions, faster and less complicated authoring and analysis of semantically described 3D content, and permits storing the 3D content in simpler databases.

The main contribution of this paper is a method of creating lightweight attribute-based built-in semantic descriptions of X3D web content. The method utilizes the standard syntax and structure of X3D documents, providing a mapping of RDFa attributes to metadata nodes in 3D models. Using the standard syntax and structure of X3D documents preserves the compatibility of the proposed approach with available X3D browsers. Due to the use of the standardized solutions, the method enables flexible semantic descriptions and widespread dissemination of content for use in a variety of 3D applications on the web.

The remainder of this paper is structured as follows. Section II presents the X3D standard in terms of metadata description. Section III provides an overview of the state of the art in the

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domain of semantic descriptions of web resources, in particular 3D web content. Section IV presents a mapping between RDFa attributes and X3D metadata nodes that enables lightweight semantic descriptions of 3D web content. Finally, Section V concludes the paper and indicates future works.

II. METADATA DESCRIPTION IN X3D

There are two types of metadata descriptions in X3D documents: metadata describing the whole X3D document and metadata describing 3D content included in the document—elements reflecting the geometry, appearance and behaviour of 3D objects in a scene.

Example X3D content described by metadata is presented in Listing 1. The first group of metadata elements—describing the X3D document—are contained in the `head`—the first X3D element preceding the `Scene` node. It may include metadata indicating additional required components (line 2) and expressing the semantics using `[name, content]` tuples (3-4)—alike in (X)HTML documents.

Listing 1. Example X3D content with metadata

```
1  <X3D ... >
2    <head><component name='Geospatial' level='1'/>
3      <meta name='title' content='Sculpture'/>
4      <meta name='subject' content='http://.../sclt.html'/>
5    </head>
6    <Shape><Sphere ...'/>
7      <Appearance><Material .../></Appearance>
8      <MetadataSet name='example_metadata' reference='http://
           www.web3d.org/spec_editors/abstract/Part01/
           components/core.html#MetadataSet' containerField='
           metadata'>
9        <MetadataString name='creator' reference='http://purl
             .org/dc/elements/1.1/creator' value='http://www.
             kti.ue.poznan.pl/' containerField='value' />
10       <MetadataString name='description' reference='http
             ://.../description' value='Example sculpture'
             containerField='value' />
11       <MetadataFloat name='Mass' reference='http://www.qudt
             .org/qudt/owl/1.0.0/quantity/Instances.html#Mass'
             value='0.5' containerField='value'>
12         <MetadataString name='Unity' reference='http
               ://.../#Unity' value='http://.../#Kilogram'
               containerField='metadata' />
13       </MetadataFloat>
14     </MetadataSet>
15   </Shape>...
```

The second group of metadata elements are structured according to the abstract `X3DMetadataObject` interface defined in the X3D specification [4]. The interface is inherited by concrete metadata nodes of different types: integer, float, double, string, as presented in Fig. 1. These nodes derive two attributes from the `X3DMetadataObject`: the `name` of the metadata field and an optional `reference` to a specification defining the unambiguous field `name`. The additional `value` attribute is an array of values of the appropriate type. A specific node is the `MetadataSet` containing an array of metadata nodes of different types. Besides inheriting from the `X3DMetadataObject`, the metadata nodes are also descendants of the abstract `X3DNode` that includes an `X3DMetadataObject` element. Hence, each metadata node may be described by a nested metadata sub-node. Furthermore, all elements included in the X3D document (concrete nodes) implement the `X3DNode` interface, thus all elements of the described virtual scene may have metadata specified.

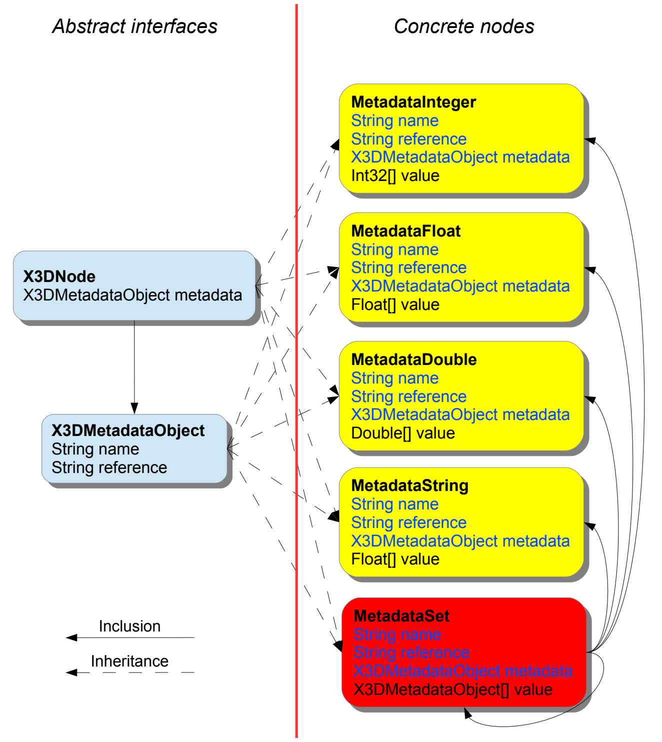

Fig. 1. X3D interfaces and metadata nodes

In the example in Listing 1, the shape is described by three elements: geometry, appearance and metadata. The whole semantics is enclosed in the `MetadataSet` and includes both simple (`subject`, `creator`, `description`—lines 9-10) as well as complex (`Mass`, 11) nested nodes. Every node is assigned a `name` and a `reference` to the `name` definition (a web document). The `containerField` associates the node with the appropriate field of its parent node.

III. SEMANTIC DESCRIPTIONS OF WEB CONTENT

In this section, the state of the art concerning semantic descriptions of web content is presented. In particular, basic techniques for describing semantics of web documents, methods of attribute-based semantic descriptions as well as semantic descriptions of 3D objects are considered. The first two domains are currently closely related to web pages, while the last one constitutes an emerging field of research on semantically described virtual and augmented reality.

A. Foundations for the Semantic Web

The primary technique for data semantics description on the web is the Resource Description Framework (RDF) [1]—a standard devised by the W3C. RDF introduces general rules for making statements about resources. Each statement is comprised of three elements: *a subject* (a resource described by the statement), *a predicate* (a property of the subject) and *an object* (the value of the property).

An example statement expressed in RDF is: "Bob (*subject*) likes (*predicate*) shopping (*object*)". According to the RDF specification [1], the subject may be either a resource identified by a URI (not necessary accessible via HTTP) or a blank node.

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The object may be either a resource with a URI or a literal. To ensure unambiguous representation of the relationship between the subject and the resource, the predicate must have a URI assigned. RDF data sets may be encoded in different formats such as XML, N-Triples, Turtle and JSON.

RDF introduces classes (as types of resources), containers and lists to provide basic concepts for semantic descriptions. However, these notions are often insufficient for describing the semantics of complex resources. To overcome limitations of RDF, the RDF Schema (RDFS) [5] and the Web Ontology Language (OWL) [6] have been proposed as W3C standards based on RDF, providing higher expressiveness for semantic descriptions of web resources, e.g., hierarchy of classes and properties, constraints, property restrictions as well as operations on sets.

While RDF and RDF-based techniques permit creation of ontologies and knowledge bases, SPARQL [7] is a language for querying RDF data sources. To provide a common space for identifiers of resources and properties on the web, a number of ontologies and knowledge bases have been proposed for various domains, e.g., describing relationships between people [8], media resources [9], images, audio, video [10], quantities, units, dimensions [11] and chemical compounds [12].

B. Attribute-based methods of creating semantic descriptions

It is often desirable to combine both resources and their semantics in a single web document, e.g., in a web profile with personal data and relationships between people. In such cases, web documents (e.g., (X)HTML) may be enriched with additional attributes describing data semantics.

Among a few approaches to attribute-based semantic descriptions of web content, the Resource Description Framework in Attributes (RDFa) is the most powerful one and has been standardized by the W3C. RDFa [2] defines a set of markup attributes extending web documents with semantic descriptions compliant with RDF:

1) `about, src`—the URI of a subject (external or embedded into the document) described by the metadata;
2) `typeof`—a list of types of the subject;
3) `property, rel, rev`—a list of predicates specifying properties, relationships and reverse relationships between resources;
4) `href, resource`—the navigable/non-navigable URI of an object resource;
5) `content`—an object resource specified as a literal overriding the value of the element when using the `property` attribute;
6) `datatype`—the optional data type of the literal, that may be specified for the `property` value;
7) `vocab, prefix`—a vocabulary/list of prefixes used to abbreviate URIs of resources and properties specified in the metadata;
8) `inList`—a list of literals/URIs associated with the predicate.

An example web page described with RDFa attributes is presented in Listing 2. The document is described by metadata in the `head` element (`title` and `creator`—lines 2-4). The presented object (a sculpture) has a URI and a type (5), properties (`subject` and `Mass`, 7-8) as well as a relationship with an external resource (an image—6). In the document, prefixes to global (1) and local (5) namespaces are defined and used.

Listing 2. An example web page with RDFa attributes

```
1  <html prefix="dc: http://purl.org/dc/terms/">
2    <head><title property="dc:title">Exhibition</title>
3      <meta name="dc:creator" content="DIT" />
4    </head>
5    <body><div about="http://example.org/sculpture" typeof="
           http://.../sculpture" prefix="dcimtype: http://purl.
           org/dc/dcmitype/ qudt: http://.../Instances.html#">
6         <img rel="dcimtype:Image" src="sculpture.gif"/>
7         <span property="dc:subject" content="sculpture"/>
8         <span property="qudt:Mass" content="0.5" datatype="
               xsd:float"/>
9    </div></body>
10 </html>
```

In some cases, it is desirable to decouple semantics from data and present it as a separate RDF document (e.g., to load into a triplestore). The Gleaning Resource Descriptions from Dialects of Languages (GRDDL) [13] is a W3C standard designed for this purpose.

Microdata [14] is another approach proposed by W3C to embed semantics into web content. Alike RDFa, Microdata describes triples comprised of the subject, property and object using attributes for specifying types, scopes, ids, properties and references. To enable common semantics on the web, some vocabularies have been defined for Microdata to describe, e.g., people, organizations, products, etc. [15][16].

Microformats [17] are a solution for describing metadata embedded into web pages, that is simpler than RDFa and Microdata. Microformats make use of the `class` and `rel` attributes to express classification and relationships for web resources. These attributes may be built into various (X)HTML elements such as `span, div, ul`, etc.

C. Semantic descriptions of 3D models

Several works have been conducted to combine X3D content with semantic descriptions. In [18], an integration of X3D and OWL using scene-independent ontologies and the concept of semantic zones have been proposed to enable querying 3D scenes at different levels of semantic details and implement a guided tour through the Venetian Palace. In [19], interfaces for annotating 3D worlds in X3D and a search module have been described. A few projects have been conducted on extending MPEG-7 with semantic annotations of 3D objects. In [20], some descriptors have been introduced to optimize specification of semantics of X3D objects, in particular their sizes, types, curvatures, etc. The works [21][22] consider a generic semantic annotation model for describing semantics of X3D content using MPEG-7. In [23], 3D digital assets in COLLADA have been combined with semantic tags to present sculptures and monuments. In [24], ontology-based RDF tags are separated but linked to 3D models via identifiers to enable web presentation of museum artefacts. A generic modelling framework for metadata based on semantic web standards and selected multimedia formats has been presented in [25]. Some core patterns have been designed for describing provenance, structure and values of objects. A video search engine for vehicles described by a set of attributes has been presented in [26]. Some other solutions are devoted to structured composition of interactive behaviour-rich 3D web applications [27]-[29], describing interactivity of 3D objects [30], their interfaces [31], as well as finding 3D objects by their properties [32].

The aforementioned projects address different aspects of semantics of multimedia content in various application domains. However, they do not focus on standardized built-in attribute-based solutions for lightweight inclusion of metadata in web resources. Embedding metadata directly into 3D content has a few important advantages in comparison to approaches that decouple resources from metadata describing them. First, with embedded metadata, 3D models are unambiguously and inextricably linked with their descriptions. Second, this enables more concise semantic descriptions as well as faster and less complicated authoring and analysis of semantically described 3D content. Furthermore, it facilitates combining the semantic descriptions of 3D content with descriptions of web pages that embed the content. Finally, it permits storing the 3D content in structurally simpler databases.

IV. MAPPING OF RDFA ATTRIBUTES TO X3D METADATA NODES

To enable lightweight attribute-based built-in semantic descriptions of 3D web content, a mapping of RDFa attributes to X3D metadata nodes is proposed in this paper. The presented approach utilizes the standard syntax and structure of X3D documents and decouples descriptions of the semantics of 3D components from descriptions of their geometry, appearance and behaviour by putting the metadata into additional elements embedded in X3D nodes (as opposed to RDFa attributes nested in HTML tags).

The mapping between the RDFa attributes and the X3D metadata nodes is depicted in Fig. 2. Example X3D content described with RDFa attributes is presented in Listing 3. The scene (lines 11-65) presents a room in a museum with a shelf (12-34) on which there is a sculpture (35-51) and a complex model of a plough (52-64). Some geometrical and behavioural elements and attributes have been omitted as they are not crucial in the context of the presented method.

Listing 3. An example X3D document with RDFa attributes

```
1  <?xml version="1.0" encoding="UTF-8"?>
2  <!DOCTYPE X3D PUBLIC "ISO//Web3D//DTD_X3D_3.0//EN" "http://
       www.web3d.org/specifications/x3d-3.0.dtd">
3  <X3D profile='Immersive' version='3.0' xmlns:xsd='http://
       www.w3.org/2001/XMLSchema-instance'
4   xsd:noNamespaceSchemaLocation='http://www.web3d.org/
        specifications/x3d-3.0.xsd' xmlns:dc='http://purl.org/
        dc/terms/'>
5   <head>
6    <meta name='dc:identifier' content='http://.../m.x3d' />
7    <meta name='dc:title' content='Museum room' />
8    <meta name='dc:created' content='2012-10-05' />
9    <meta name='semanticDescription' content='http://www.w3.
         org/TR/rdfa-syntax/' />
10  </head>
11  <Scene DEF='MuseumRoom'>
12   <Shape DEF='VirtualShelf'>
13    <Appearance>...</Appearance><Box />
```

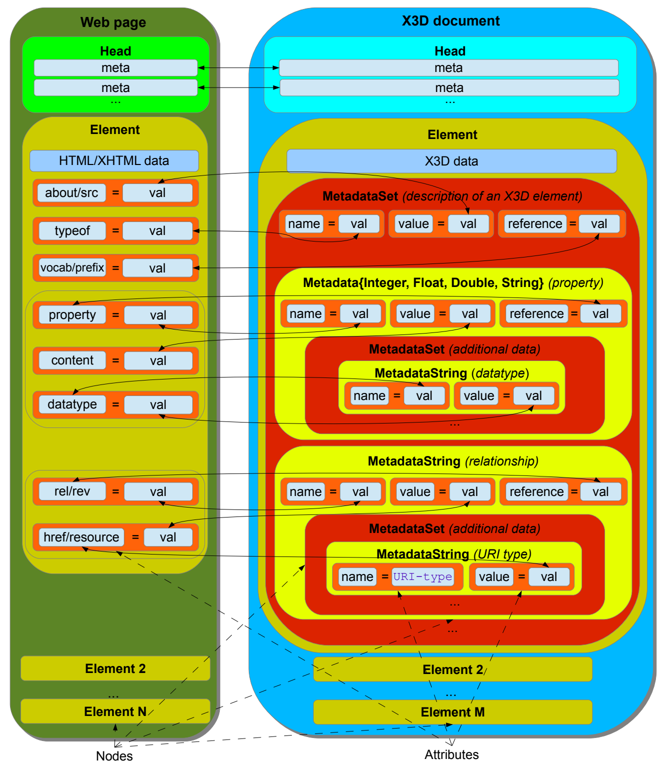

Fig. 2. Mapping between RDFa attributes and X3D metadata nodes

```
14  <MetadataSet>
15   <MetadataSet name='http://www.w3.org/ns/ma-ont.rdf'
        value='VirtualShelf'>
16    <MetadataString name='description' value='A model ...'
          reference='property' />
17    <MetadataString name='hasFormat' value='X3D' reference
         ='property' />
18    <MetadataString name='creationDate' value='2012-10-02'
          reference='property'>
19     <MetadataString name='datatype' value='xsd:date' />
20    </MetadataString>
21    <MetadataString name='hasContributor' reference='
         property'>
22     <MetadataSet name='http://www.w3.org/.../ns.rdf'>
23      <MetadataString name='fn' value='DIT' reference='
           property' />
24      <MetadataString name='tel' value='+48-618-480-549'
           reference='property' />
25     </MetadataSet>
26    </MetadataString>
27   </MetadataSet>
28   <MetadataSet name='http://example.org/museum/types/
        shelf' value='http://example.org/museum/shelf'>
29    <MetadataString name='dc:medium' value='wood metal'
         reference='property' />
30    <MetadataString name='dc:creator' value='http://.../
         carpenter' reference='rel'>
31     <MetadataString name='URI_type' value='href' />
32    </MetadataString>
33   </MetadataSet>
34  </MetadataSet></Shape>
35  <Transform DEF='VirtualSculpture'>
36   <Appearance>...</Appearance>
37   <IndexedFaceSet>...</IndexedFaceSet>
38   <MetadataSet>
39    <MetadataSet value='http://.../museum/sculpture'
40     reference='foaf: http://xmlns.com/foaf/spec/#term_
         qudt: http://www.qudt.org/.../Instances.html#'>
41    <MetadataFloat name='qudt:Mass' value='1.5' reference
         ='property' />
42    <MetadataString name='foaf:depiction' value='
         VirtualSculpture' reference='rel'>
43     <MetadataString name='URI_type' value='resource' />
44    </MetadataString>
45   </MetadataSet>
```

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```
46    <MetadataSet value='VirtualSculpture' reference='http
        ://xmlns.com/foaf/spec/#term_'>
47     <MetadataString name='depicts' value='http://.../
         museum/sculpture' reference='rel'>
48      <MetadataString name='URI_type' value='href' />
49     </MetadataString>
50    </MetadataSet>
51   </MetadataSet></Transform>
52   <Transform DEF='VirtualPlough'>
53    <Transform DEF='VirtualBox' /><Transform DEF='
        VirtualHook' />
54    <Transform DEF='VirtualCylinder'>
55     <MetadataSet value='VirtualCylinder'>
56      <MetadataString name='dc:hasPart' value='
          VirtualPlough' reference='rev'>
57       <MetadataString name='URI_type' value='resource' />
58      </MetadataString>
59     </MetadataSet></Transform>
60    <MetadataSet value='VirtualPlough'>
61     <MetadataString name='dc:hasPart' value='
         VirtualCylinder' reference='rel'>
62      <MetadataString name='URI_type' value='resource' />
63     </MetadataString>
64    </MetadataSet></Transform>
65  </Scene>
66 </X3D>
```

For the first type of metadata, the mapping is easy, as the resulting meta elements are equivalent to meta elements in a web page (5-10). The standard to which a particular semantic description conforms may be indicated by the appropriate `meta` node (9) to enable proper interpretation of the document.

The second type of metadata in X3D documents, in the presented method, is used for describing the semantics of both real objects and their corresponding 3D models. The mapping is performed between RDFa attributes that are intended for (X)HTML web pages and metadata nodes of X3D documents. As a web page may include many (X)HTML elements with RDFa attributes, an X3D document may incorporate a number of XML nodes corresponding to different components of a 3D scene, which may be described by metadata nodes.

The primary unit of the semantic description of such resources is the `MetadataSet` node. The presented method encompasses all the RDFa attributes mentioned in Section III-B, putting their names and values into attributes of X3D metadata nodes. A semantically described X3D element contains a `MetadataSet` node (in addition to nodes expressing its geometry, appearance and behaviour) that may include multiple metadata sub-nodes to which particular RDFa attributes are mapped as follows:

1) `typeof` and `about/src` are mapped to the `name` and `value` attributes of the `MetadataSet`, respectively. Both attributes are optional and they are used in the same way for real objects such as a worker, a sculpture, a museum (28), and virtual objects, e.g., a document, an image, a 3D model (15). The type should be defined by a data structure with properties. Data types and attributes used in the presented example belong to FOAF, Media Resources, Dublin Core and QUDT domains that are intended for RDF. New item properties may be added to the `MetadataSet` independently of the specified data type.
   The optional `value` attribute specifies the URI of the described web resource (not necessary navigable). Since the method enables description of the semantics of real objects and their 3D models, both types of resources are referenced in the same manner. If a particular 3D component is to be linkable, it has to be assigned a URI in the X3D `DEF` attribute (11, 35). Such a solution has three important implications. First, it conforms to the language specification. Second, it permits referencing both local 3D resources—through their URIs—and remote nested 3D components—preceding their URIs by HTTP URIs of their parent web resources. Third, any real or virtual object may be described by any `MetadataSet` independently of their relative location on the web. In particular, a `MetadataSet` no longer needs to describe only the parent 3D component.
   If the `about/src` attribute is not mapped for a particular `MetadataSet` node (no URI of the described resource is specified), the `MetadataSet` represent a blank node (22-25). Blank nodes are used in semantic descriptions when a subject is in a relationship with a complex resource described by multiple fields, that has no URI specified. In the presented example, a blank node is used to describe the creator of the 3D model of the shelf.
2) `vocab` (46), `prefix` (40)—are optionally mapped to the `reference` attribute of the `MetadataSet`. Both the attributes are applied to the entire scope of the node, including all its descendants. The `prefix` attribute may include a list. In the presented example, these attributes simplify using FOAF (47) and quantity (41) definitions.
3) `property/rel/rev` and `content/href/resource` attributes are mapped to the `name` and `value` attributes of a typed node. For properties, nodes of all types may be utilized (integer, float, double, string), while relationships (`rel` and `rev` attributes) are only reflected by `MetadataString` nodes. To differentiate navigable from non-navigable URIs of objects given in relationships, an additional `MetadataString` sub-node is introduced with the name set to `URI-type` and the value set to `href` or to `resource`. In the presented example, relationships describe links to external content (30, 42, 47) and hierarchical dependencies between 3D components (56, 61), while properties describe various features of resources such as descriptions, formats, medium, etc. (16-18, 29). When no `value` attribute is given for the property, the descendant blank node is used as its value, e.g., contributor described by multiple properties (22-25). To describe some additional aspects of a property, sub-nodes may be introduced, e.g., for mapping the RDFa `datatype` attribute when typed metadata nodes are not sufficient to express sophisticated types (19).
4) `inList`—since X3D metadata nodes may have several values separated with spaces, this attribute is simply mapped to such an array. In the example, the shelf is made of wood and metal (30).

The meaning of particular X3D attributes in the proposed method differs minimally from their semantics described in the X3D specification. However, X3D metadata nodes have been designed for simple metadata description and not for use with Semantic Web standards. The small extension of the meaning of their attributes enables full adoption of the presented technique without disturbing the current syntax and structure of X3D and conflicting with widely-used 3D browsers.

An approach alternative to the presented one could be based on the ordinary extension of X3D syntax with RDFa attributes embedded into particular X3D nodes (alike in HTML). Although little more concise, such solution is outperformed by the proposed method in terms of the compatibility with available X3D browsers and flexibility in describing 3D components distributed across the web. Despite the difference between the syntaxes of these approaches, the resulting semantic descriptions are equivalent in terms of expressiveness.

V. Conclusions and Future Works

In this paper, a method of creating lightweight attribute-based built-in semantic descriptions of 3D web content has been proposed. Although several solutions have been developed for the Semantic Web, they are intended mostly for describing standard web pages. Lack of commonly accepted approach to describing semantics of 3D resources is one of the important obstacles for widespread creation, dissemination and reuse of 3D content on the web.

The presented method combines RDFa with X3D and it is compliant with well-established web standards. It provides a bidirectional mapping between RDFa attributes that are used in typical web pages and metadata nodes used in X3D documents without introducing any modifications to their standard syntax and structure. Both descriptions are semantically equivalent. Embedding semantics into the described documents permits adoption of the method without the need for implementing additional repositories and tools.

Possible directions of future research incorporate several facets. First, additional mappings should be elaborated for other formats of attribute-based semantic descriptions, in particular for Microdata and Microformats. Second, the proposed approach stresses the compatibility with available 3D browsers but not with RDFa parsers. To harvest metadata from semantically described X3D documents and evaluate the proposed method, a GRDDL agent should be implemented (e.g., based on XSLT transformations). Third, a SPARQL engine could be developed to enable querying X3D models. Finally, the method may be combined with semantics derived from spatial, temporal, structural, logical and behavioural components of 3D models.

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