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Transforming 3D Models to Semantic Web Representation

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Abstract. The purpose of the present paper is to research a rule-based approach for transforming X3D (*eXtensible 3D*) models to RDF (*Resource Description Framework*). The transformation is performed by using the *RDF Mapping Language* (RML). Its advantages are summarized, which are mainly due to the fact that the rules created build a knowledge base. By applying SPARQL (*SPARQL Protocol and RDF Query Language*) queries to it, the possibility of explore in order to validate and improve the defined RML rules themselves, is pointed out. An approach for reversing from the RDF triples to the original X3D in a unique way is considered, and the types of SPARQL queries needed for its implementation are systematized.

Rules are formulated for all elements defined in the X3D schema, their attributes and properties are described. Their accessibility is ensured. The conversion of X3D models to RDF is confirmed to be consistent with guidelines and best practices for creating accessible, understandable, and reusable ontologies on the Web. The systematized SPARQL query types for reversing from RDF triples to the original X3D are checked for specific elements and sample data, and the obtained results establish their correctness. The prerequisites and limitations of the represented approach are explained.

The proposed approach allows building a comprehensive knowledge base that includes the RML rules, the transformed X3D models and the domain-specific ontology and its use to analyzing data and semantic reasoning. The electronic libraries that include 3D content could take advantage from the benefits and possible future applications of the solutions discussed in this study.

Key-words: Ontology; RDF mapping language; X3D models.

1. Introduction

The Semantic web [1] enables the transformation of the World Wide Web into a global knowledge base that includes multimedia content with formal descriptions of its semantics represented in a human-understandable and machine- readable and processible manner. It is built on standards used to represent content of any type – the *Resource Description Framework* (RDF) [2], the *RDF Schema* (RDFS) [3] and the *Web Ontology Language* (OWL) [4], based on RDF and ensuring even higher expressiveness – classes and properties with relationships and hierarchies that allow comprehensive content description.

The standards are conceptually based on descriptive logic and provide an opportunity for the creation of ontologies about a certain domain, covering domain-specific classes, properties and relationships between them. Gruber defines the term ontology as "a formal explicit specification of a conceptualization" [5]. The conceptualization implies a description of a set of objects and concepts, knowledge about them, facts, rules and relationships between them [6]. Ontology-based content descriptions can be subject to automated queries using the SPARQL (SPARQL Protocol and RDF Query Language) [7] and reasoning using the *Semantic Web Rule Language* (SWRL) [8].

In connection with the implementation of the idea of the Semantic web, there is a need for approaches and tools that allow data available in different formats to be transformed into an RDF model. For this purpose, the *RDF Mapping Language* (RML) is defined, which serves to state custom mapping rules from heterogeneous data structures and serializations to the RDF data model [9]–[11]. It is based on R2RML (RDB to RDF Mapping Language), which is the W3C standard for expressing custom mappings from relational databases to RDF [12]. RML aims to expand its applicability and scope by adding support for data in other structured formats such as CSV, TSV, XML (eXtensible Markup Language), JSON. The main advantages over other data transformation languages (such as XSLT [13], XSPARQL [14]) in RDF are:

- Clarity of purpose of defined matching rules;
- Reuse analogous data rules that describe the same model but are serialized in different initial formats.

In addition, applications are developed that facilitate the formulation and processing of rules [15].

Semantic web technologies are widely used in developing intelligent web applications, including building digital libraries to provide an efficient way to store and manage information resources [16]–[19]. From the perspective of current trends in the development of electronic libraries [20]–[25], 3D models can be considered as an important media information format in an e-library. Through them, it is possible to implement virtual and augmented reality, which is gaining popularity in the public libraries, since it allows enrichment of the content of resources and it is successfully used as a learning tool [26]–[28].

In the present paper, X3D (eXtensible 3D) is considered, which is a widely used standardized 3D format for web-based 3D environments. It is developed by the Web3D consortium as a successor to VRML (Virtual Reality Modeling Language). X3D file format support includes XML (.x3d), Classic VRML (.x3dv), Compressed Binary Encoding - CBE (.x3db), JSON. Therefore, the availability of defined rules for matching via RML allows the conversion of X3D models represented via XML and JSON into RDF, which motivates the present study.

The rest of this paper is organized as follows. Section 2 reviews similar studies related to X3D conversion or RML application. Section 3 is devoted to the proposed rule-based conversion of X3D models to RDF – its benefits, possibility for reversing the initial X3D, prerequisites and limitations for its implementation, and availability of the created rules are considered. In Section 4, RML rules are discussed in terms of building a comprehensive knowledge base that includes them, the transformed X3D models, and the domain-specific ontology. Section 5 contains a summary of present research and directions for future work.

2. Related Work

For the purposes of the present study, existing approaches for transforming 3D models to RDF are explored. They can be systematized according to the final result to be achieved – RDF descriptions of the metadata of the 3D model or ontology.

• RDF descriptions of the metadata of 3D models;

Approaches based on the RDFa [29] and Microformat and Microdata [30] schemes are developed to create RDF descriptions of X3D model metadata. A correspondence between RDFa attributes and metadata elements in X3D models is described in [31]. In [32], Microformat and Microdata schemes are proposed for describing X3D metadata elements. In both approaches, representations of X3D models retain their compatibility with available 3D browsers, therefore no additional tools are necessary for their visualization, but a need arises for their RDF conversion.

RDFa annotations of 3D models are applied in [33] in an HTML web page, maintaining a relationship between the 3D content and its RDFa-based web annotation. As a result, metadata descriptions of 3D models are compatible with RDFa parsers.

• Representation of 3D models as an ontology.

Some researchers propose ontology-based solutions for specific domains. In [34], an ontology OROnto (*Operating Room Ontology*) is developed, designed to model hospital scenarios for the purpose of building a VR (*virtual reality*) system. An ontology for 3D cultural objects is suggested in [35].

A domain-independent representation of 3D models is achieved by developing the X3D Ontology [36]–[38]. Its design conforms to the international standard for *Extensible 3D* (X3D) graphics, specifically the *X3D Unified Object Model* (X3DUOM). The classes and relationships between ontology content components are analogous to X3D elements and attributes. X3D ontology enables conversion of X3D models into triples and thus exploiting capabilities to search and reuse 3D models and scenes in web repositories, reasoning 3D content, and analyzing 3D content with complex and precise queries. The transformation proposed in [39] is based on XSLT (*eXtensible Stylesheet Language Transformations*).

On the other hand, from the conducted exploration of the existing research could be concluded that the emergence of RML has attracted research interest, and editors are developed to support the creation of RML rules and processors for their execution. In [15], an RMLEditor is proposed with a visual user interface that allows mappings to be easily defined for obtaining an RDF representation of the relevant data.

In [40], an RML processor is implemented that can convert various formats of sensor data into information expressed through RDF.

In [41], an RML interpreter SDM-RDFizer for transforming data in different formats into an RDF graph, is proposed. SDM-RDFizer implements algorithms to perform the logical operators between mappings in RML to ensure scalability in terms of data volume and degree of duplication.

In [42], RML-star is a proposed which is an extension of RML designed to express custom mappings from heterogeneous data structures and serializations to RDF-star [43], which in turn extends RDF with a convenient way to formulating statements about other statements.

In the present paper, a rule-based approach to transform X3D models to RDF is proposed. Its advantages derive from the fact that the created RDF rules build a knowledge base, which in turn implies the possibility of validating and improving the defined RML rules themselves; reversing from the RDF triples to the original X3D in an unambiguous way using appropriate SPARQL queries; analyzing data and reasoning.

3. Rule-based Transformation of X3D Models to RDF

The proposed approach for rule-based transformation of X3D models to RDF is illustrated in Fig. 1.

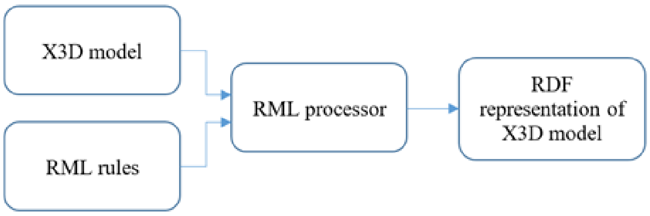

Fig. 1. Rule-based transformation of X3D model to RDF.

The present study provides RML rules for transformation X3D model to RDF. In order to perform efficient processing and execution of the rules by the RML processor, it is possible to perform to follow the steps:

- Extracting the rules for the elements that are present in the description of the specific X3D model;
- The rules regarding the selected items to be submitted to the RML processor.

Their execution can be done in parallel.

For a given `Element` of the X3D scheme, the necessary rules can be systematized as follows:

A. Rules that generate statements about the resource belonging to a certain class (Listing 1, available from [44]).

   The resulting RDF statements have the form:

   `:Element_id a owl:NamedIndividual, x3do:Element.`

   The template defined on line 7 specifies the subject of the generated RDF triple; the predicates are set by the properties on lines 8 and 11; the objects - from the constants of lines 9 and 12.

B. A rule that generates a statement about the parent element (Listing 2, available from [44]).

   RDF statements of the type are generated:

   `:Element_id x3do:hasParent :Parent_Element_id .`

   For rules of type B, C, and D, the template defined on line 7 determines the subject of the generated RDF triple; the predicate are set by the property on line 9; the object - from the template on line 10. Templates are XPath expressions.

C. Rules that generate statements about what the successor elements are (Listing 3, available from [44]).

   As a result, RDF statements are constructed that look like this:

   `:Element_id x3do:hasChildren :ChildElement _id .`

D. Rules that generate resource property statements corresponding to element attributes (Listing 4, available from [44]).

   The resulting RDF statements have the form:

   `:Element_id x3do:attribute` "`attribute_value`".

   Listing 5 (available from [44] shows RML rules for the Sphere element that generate statements for the properties "a" (indicating that the resource is an instance of a class), `x3do:hasParent`, `x3do:radius`, and rules for the element Shape intended for statements about the property `x3do:hasGeometry`.

   An example result of the execution the rules in Listing 5 is as follows in Turtle (*Terse RDF Triple Language*):

```
:Sphere_1 a owl:NamedIndividual, x3do:Sphere;
          x3do:hasParent :Shape_1 .
          x3do:radius ”5”.
:Sphere_2 a owl:NamedIndividual, x3do:Sphere;
          x3do:hasParent :Shape_3.
          x3do:radius “2”.
:Shape_1 x3do:hasGeometry :Sphere_1.
:Shape_3 x3do:hasGeometry :Sphere_2.
```

3.1. Advantages

The main advantages of the examined approach in the present paper consist in the possibility of building a comprehensive knowledge base that includes the RML rules, the transformed X3D models and the domain-specific ontology; the possibility of its usage for data analyzing and reasoning; 3D content validation; extensibility and updateability; reversing from the RDF triples to the original X3D. These advantages are discussed in detail below. At the end of this section, the main distinguishing features of the proposed approach are summarized and compared with those of similar ones.

A. The proposed transformation of X3D models to RDF is based on rules defined by using RML. As a result, the advantages of RML over other data transformation languages mentioned in the introduction of this paper are exploited. The existing solution for transforming X3D models into an ontology [39] is based on XSLT. Unlike RML, XSLT is a language primarily designed to transform XML documents into other XML documents [13]. Therefore, constructing RDF triples (represented in formats other than RDF/XML) does not serve its primary designation. For this reason, applying it for this purpose results in code that is more difficult to read than the RML rules. On the other hand, RML is created precisely for obtaining RDF statements, and RML processors allow choosing in which format to export the generated statements from the RDF model. An RML rule has a clear structure, each part of which corresponds to a specific part of the RDF triples that are generated from it. In this way, the presence of inaccuracies can be traced with less effort.

B. The representation of the 3D models after transformation with the proposed rule-based approach is in correspondence with guidelines and best practices for creating accessible, understandable and reusable ontologies on the Web [45].

In [45], recommendations and guidelines are formulated and summarized in order to avoid negative consequences of creating ontologies that are difficult for researchers to find, access and understand due to problems with class and property identifiers, version conflicts, missing metadata. In this regard, the following recommendations are observed:

- Transparent class and property identifiers are set;
  The main advantage of this approach is ease of interpretation. The class and property identifiers in the X3D ontology are defined according to the elements and their attributes in the X3D schema.
- Ontology version could be specified;
  Setting the version of the ontology is done through the `owl:vesrionIRI` and `owl:vesrionInfo` properties. For this purpose, the following rules are defined:

```
rules:OntologyMap a rr:TriplesMap;
  rml:logicalSource [
    rml:source "HelloWorld.x3d";
    rml:referenceFormulation ql:XPath;
    rml:iterator "/" ];
  rr:subjectMap [
    rr:template :;
    rr:class owl:Ontology ];
  rr:predicateObjectMap [
    rr:predicate owl:vesrionIRI;
    rr:objectMap [rr:constant <http://example.org/1.0.0>]];
  rr:predicateObjectMap [
    rr:predicate owl:vesrionInfo;
    rr:objectMap [ rr:constant "1.0.0" ] ].
```

  This rules generate triples to represent the ontology's metadata about its version:

```
<http://example.org> a owl:Ontology;
   owl:vesrionIRI <http://example.org/1.0.0>;
   owl:vesrionInfo "1.0.0".
```

- Ontology metadata are represented.

The proper understanding and usage of the ontology requires the description of appropriate metadata such as license, creator, contributor, creation date, and previous version to trace the origin of the ontology and compare it to earlier versions; namespace URI; summary, links to related resources, etc. For this reason, the rules for the recommended and optional metadata are added, which are associated with the ontology regarding the terms of its use and understanding of its origin.

C. Validation of 3D content.

The RML rules themselves are represented by RDF triples and the set of all RML rules for transforming X3D models can be considered as a knowledge base that can be reused and adapted. In addition, requests can be executed to it for validation and improvement of the defined RML rules. Instead of validating the generated RDF triples, these rules which determine how the RDF triples should be generated, could be examined. This approach is more effective because the execution of one rule could lead to the creation of multiple RDF triples. For example, to find the rules that generate RDF triples based on the attributes of the elements, the following SPARQL query can be applied:

```
PREFIX rr:  <http://www.w3.org/ns/r2rml#>
PREFIX rml:  <http://semweb.mmlab.be/ns/rml#>
SELECT DISTINCT ?rule ?element ?subject ?predicate ?attribute
WHERE {?rule rml:logicalSource ?i ;
               rr:subjectMap ?sm;
               rr:predicateObjectMap ?pm .
     ?i rml:iterator ?element .
     ?sm rr:template ?subject .
     ?pm rr:objectMap ?o ;
              rr:predicate ?predicate .
     ?o rml:reference ?attribute .  }
ORDER BY ?rule
```

Part of the result from the execution of this SPARQL query to the knowledge base, built by RML rules for transforming the exemplary X3D file from Fig. 2, is shown in Table 1.

Table 1. Finding the rules that generate RDF triples based on the attributes of the elements

rule	element	subject	predicate	attribute
X3DMap	"/X3D"	X3D	profile	""@profile
X3DMap	"/X3D"	X3D	version	""@version
BackgroundMap	"/X3D/Scene/Background"	"http://example.org/{"@id}	skyColor	""@skycolor
TransformMap	"/X3D/Scene/Group/Transform"	"http://example.org/{"@id}	DEF	""@def
TransformMap	"/X3D/Scene/Group/Transform"	"http://example.org/{"@id}	translation	""@translation
TransformMap	"/X3D/Scene/Group/Transform"	"http://example.org/{"@id}	rotation	""@rotation

Similarly, the rules that generate RDF triples based on possible successors to the elements by using a SPARQL query, could be found.

D. Extensibility and updateability.

The set of created rules can be expanded with new rules. The reasons that could give rise to this need are the development of the X3D standard and/or the X3D ontology. From the general view of the rules shown in Figures 2–5, it can be concluded that rules for new elements and attributes can be supplemented. Adding new and updating existing rules can be done using statements from SPARQL Update [46], since the rules themselves represent RDF triples and can be manipulated by executing SPARQL queries.

Another eventual possibility for the research problem under consideration is the *Data Format Description Language* (DFDL) language [47].

It is intended for description of text and binary data formats and it have the status of the recommended specification of the Open Grid Forum [48]. DFDL is designed as an extension of the XML Schema [49] language which provides an easy transformation of text and binary data into the corresponding XML document. Therefore, the use of DFDL would allow the conversion of different file formats to X3D models to RDF/XML. But in this case, it will not be possible to take advantage of the benefits provided by the built knowledge base of the created rules themselves, justified in this section of the present paper.

Table 2 summarizes and compares the main distinguishing features of the proposed approach and similar ones.

Table 2. Comparison of the proposed approach with other similar ones.

Approach to Transforming	**Result from transforming**	**Applied technology**	**Possibility for execution of SPARQL queries to validate, expand, update rules**
(Flotynski and Walczak, 2013a)	RDF descriptions of metadata	RDFa	X
(Flotynski and Walczak, 2013b)	RDF descriptions of metadata	Microformat, Microdata	X
(Seo et al., 2015)	RDF descriptions of metadata	RDFa	X
(Flotyński *et al.*, 2019)	X3D ontology	XSLT	X
Proposed in the present paper approach	X3D ontology	RML	√

3.2. Obtaining of the original X3D

The task of obtaining the initial data representation is discussed in [50], where the authors propose Reversing RML, but for column-based data sources. The main reason for generating the original X3D is to provide its reuse, which also includes processing the data in their natural format, for example, in order to be visualized with the available software tools.

The description of an arbitrary element of an X3D model can be divided into three parts indicated below with a general view of SPARQL queries, which retrieve the necessary data from the generated RDF triples.

Part 1: Finding the parent element of a given element of type `Element_type`;

SPARQL query for part 1: Query for finding the identifier of the parent element `?parent_id` of the element of type `Element_type` with identifier `?element_id` has the following general view:

```
PREFIX rdf:  <http://www.w3.org/1999/02/22-rdf-syntax-ns# >
PREFIX x3do:  <https://www.web3d.org/specifications/X3dOntology4.0# >
    SELECT ?element_id ?parent_id ?parent_type
    WHERE { ?element_id rdf:type x3do:Element_type;
              x3do:hasParent ?parent_id .
          ?parent_id rdf:type ?parent_type .
    FILTER (?parent_type != owl:NamedIndividual ) .  }
```

The result of its execution for the RDF triples obtained after transforming the sample file of Fig. 2, if *Element_type* is set to `Appearance`, is illustrated in Table 3.

Table 3. Result from SPARQL query for Part 1 for the `Appearance` elements

element_id	parent_id	parent_type
Appearance_1	Shape_1	Shape
Appearance_2	Shape_2	Shape

Part 2: Specifying the attribute names of a given element of type `Element_type` and their corresponding values;

SPARQL query for part 2: Query for finding the attribute names and values of the element of type `Element_type` with identifier `?element_id` has the following general view:

```
PREFIX rdf:  <http://www.w3.org/1999/02/22-rdf-syntax-ns# >
PREFIX x3do:  <https://www.web3d.org/specifications/X3dOntology4.0# >
    SELECT ?element_id ?attribute_name ?attribute_value
    WHERE { ?element_id rdf:type x3do:Element_type ;
              ?attribute_name ?attribute_value .
    FILTER (?attribute_name != rdf:type &&
       ?attribute_name != x3do:hasParent  &&
      !REGEX(STR(?attribute_name),"has")).}
```

The result of its execution for the RDF triples obtained after transforming the sample file of Figure 2, if *Element_type* is set to `Text`, is illustrated in Table 4.

Table 4. Result from SPARQL query for Part 2 for the Text elements

element_id	attribute_name	attribute_value
Text_1	DEF	"TextMessage"
Text_1	string	""Hello" "world!""

Part 3: Identifying the successor elements a given element of type Element_type.

SPARQL query for part 3: Query for finding the types and the identifiers of the successor elements a given element of type `Element_type` with identifier `?element_id` has the following general view:

```
PREFIX rdf:  <http://www.w3.org/1999/02/22-rdf-syntax-ns# >
```

```
PREFIX x3do:  <https://www.web3d.org/specifications/X3dOntology4.0# >
PREFIX owl:  <http://www.w3.org/2002/07/owl# >
    SELECT ?element_id ?property_name
           ?child_element_id ?child_element_type
    WHERE {?element_id rdf:type x3do:Element_type ;
                        ?property_name ?child_element_id .
           ?child_element_id rdf:type ?child_element_type .
    FILTER (?property_name != x3do:hasParent &&
           REGEX(STR(?property_name ),"has")&&
           ?child_element_type != owl:NamedIndividual ) .  }
```

The result of its execution for the RDF triples obtained after transforming the sample file of Figure 2, if *Element_type* is set to Shape, is illustrated in Table 5.

Table 5. Result from SPARQL query for Part 3 for the Shape elements

element_id	property_name	child_element_id	child_element_type
Shape_1	hasGeometry	Sphere_1	Sphere
Shape_1	hasAppearance	Appearance_1	Appearance
Shape_2	hasGeometry	Text_1	Text
Shape_2	hasAppearance	Appearance_2	Appearance

According to the XSD schema of X3D, the elements have sub-elements and/or attributes without being able to have textual content. Therefore, the listed parts provide a complete description of a given element. However, `Script` elements are an exception. In the ontology, the textual content of the element is represented by the property `x3do:description`, therefore it should be included in the result of a SPARQL part 2 query for the Script elements.

The execution of the SPARQL queries is done by using the Protg ontology editor (https://protege.stanford.edu).

3.3. Prerequisites and limitations

The proposed implementation of RML rules assumes the presence of an attribute id for each XML element. According to XML 1.0 [51], this attribute is a unique identifier that unambiguously identifies elements in order to support processing of XML documents. This supposition requires preprocessing of the XML content to provide element identifiers. Defining a unique value of the attribute id for elements is formulated as a good practice [52] for XML content authors who create material in different languages. The mentioned advantages are also useful in cases of conversion ("translation") of XML documents into other formats and models. The identifier allows the content to be reused efficiently (for example, in updates); to trace content back to its original source.

The successful execution of the rules requires the part `rml:logicalSource` of each rule, which contains:

`rml:source` "`HelloWorld.x3d`"

to be set to the location and the name of the specific *.x3d* file.

The : prefix must be set to include the concrete location and the name of a *.ttl* file resulting from the transformation:

```
@prefix :  <http://example.org/filepath/filename# > .
```

By this way uniform identifiers of resources URIs are provided.

Rules are formulated for all elements defined in the X3D schema, i.e. their attributes and properties are described.

3.4. Availability

The rules for transforming each element of the X3D scheme are in a separate file. They are published and available from github address https://github.com/tsvetankageorgieva/RMLrules_X3D_to_RDF. The file *HelloWorld.rml.ttl* contains the translation rules for the example file available at https://www.web3d.org/x3d/content/semantics/examples/HelloWorld.x3d (Fig. 2).

Fig. 2. Exemplary file available at (Web3D Consortium, 2020) with added id attribute of the elements.

4. RML Rules in Building Comprehensive Knowledge Base

3D models are used for illustrating by visualization of objects in various domains such as electronic libraries, e-learning, cultural and historical heritage, etc. There is a trend to represent information from these subject areas in the form of a domain-specific ontologies using semantic web technologies [53]–[58]. Linked data technologies allow the enrichment of these ontologies with the descriptions of the transformed X3D models. Fig. 3 shows the construction of a complete knowledge base, which consists of:

- RML rules for transforming X3D models in RDF;

  RML rules have to be executed by using an RML processor in order to transform the X3D models and their representation through RDF descriptions.

- 3D models represented by X3D ontology;

- Domain-specific ontology.

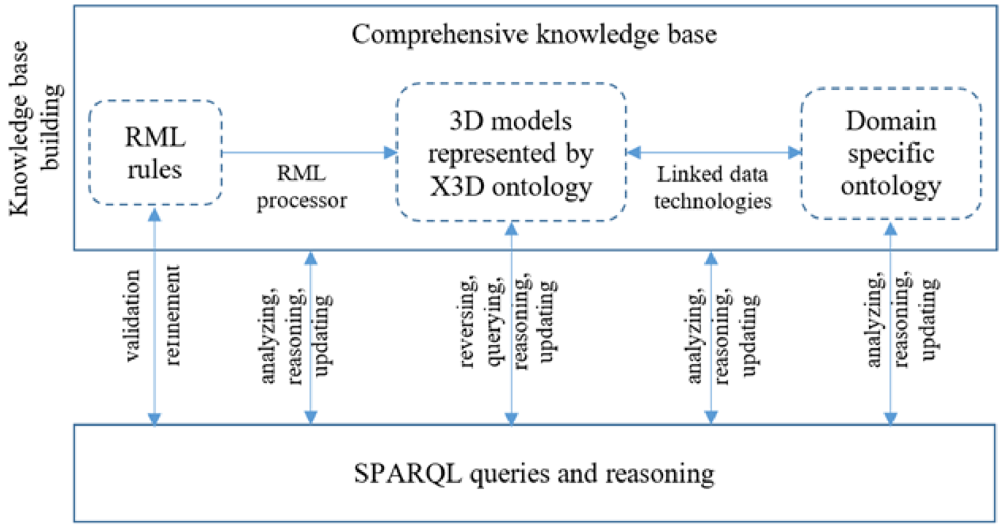

Fig. 3. Building a comprehensive knowledge base and using it to analyzing data and semantic reasoning.

The transformed X3D models are associated with the descriptions of other data from the concrete domain through the Semantic web technology – linked data. For example, if X3D models are be stored in digital repository and designed to implement virtual and augmented reality to support e-learning, than their descriptions may be linked to data about their authors; the learning content topics for which they are used; the learners who use them, and others from a domain-specific ontology.

SPARQL queries and SWRL rules are executed to:

- The comprehensive knowledge base and the domain-specific ontology for the purpose of analysis, reasoning, updating;
- RML rules for their validation and improvement;
- 3D models represented by X3D ontology for obtaining the initial X3D, extracting specific information, reasoning, updating.

As a result, the built knowledge base allows future use, for example for:

- Suggesting appropriate SPARQL queries to the resulting knowledge base with the purpose to analyzing data and semantic rezoning;
- Exploring a data analysis approach that combines executing SPARQL queries to extract relevant properties and compute weights together with applying a data mining algorithm.

As an example, it can be mentioned the exploration of an approach to discover hidden, previously unknown dependencies and patterns in 3D models data used for VR and AR in e-learning environments and domain-specific ontology data in order to improve the offered learning content. For this purpose, information on the success rate of learners and feedback from them can be included and clustering algorithms can be implemented in order to identify similar clusters; association analysis to determine whether the presence of certain elements and/or characteristics of the 3D models is detected as a prerequisite or consequence of other elements of the data; classification in pre-defined categories that may be related to the thematic of the learning content, the satisfaction of the learners, etc.

5. Conclusions

The present study is devoted to an RML rule-based approach for transforming X3D models to RDF. Using the language RML provides clarity of the purpose of the defined mapping rules to set compliance and possibility for reusability when serializing to different native formats. The transformation with the proposed approach is consistent with guidelines and best practices for creating accessible, understandable, and reusable ontologies on the Web. Its advantages due to the fact that the created rules build a knowledge base are confirmed.

Furthermore, an approach is described for reversing from the RDF triples to the original X3D in an unambiguous way. For this purpose, SPARQL queries are executed to the RDF triples obtained after the conversion. Perspectives related to building a comprehensive knowledge base that includes the RML rules, the transformed X3D models, and the domain-specific ontology are outlined.

When building digital repositories maintaining information on different domains, including in the form of 3D content, it would be useful to take into account the possibilities proposed by the present study.

Our future work includes adapting RML rules for JSON format; using SWRL rules to reasoning the resulting post-transformation RDF triples to achieve acquisition of X3D content properties that are not explicitly defined but can be inferred from the obviously defined properties.

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