The final publication is available at Springer via http://dx.doi.org/10.1007/978-3-642-41687-3_23

Conceptual Semantic Representation of 3D Content

Jakub Flotyński, Krzysztof Walczak

Poznań University of Economics,
Niepodległości 10, 61-875 Poznań, Poland
{flotynski,walczak}@kti.ue.poznan.pl
http://www.kti.ue.poznan.pl

Abstract. The complexity of 3D content makes its creation accessible to professional IT developers equipped with specific software tools and hardware devices, but it is generally inaccessible to non-expert users. The Semantic Web approach enables description of web resources with commonly used concepts. However, the use of semantic concepts may also facilitate creation of interactive 3D content. In this paper, a new approach to conceptual semantic representation of 3D content is proposed. The presented solution permits modelling of 3D content at an arbitrarily high level of semantic abstraction with the use of domain-specific ontologies. Thanks to the compliance with well-established solutions for semantics and 3D content representation, the proposed approach can facilitate widespread creation, dissemination and reuse of 3D content by non IT-professionals in a variety of applications domains.

Key words: 3D web, Semantic Web, 3D content, semantic modelling, ontology

1 Introduction

Widespread use of interactive 3D technologies and multimedia systems, including virtual reality (VR) and augmented reality (AR), has been recently enabled by significant progress in hardware performance, rapid growth in the available network bandwidth, as well as the availability of versatile input-output devices. The primary element of VR/AR applications is three-dimensional content. The creation of interactive 3D content is typically more complex than the creation of of typical web resources, as it may concern a variety of aspects—geometry, structure, space, appearance, logic and behaviour. Hence, this process is currently accessible mainly to professional developers equipped with specific 3D modelling tools and hardware devices (e.g., 3D scanners), and it is generally inaccessible to non IT-professionals. The increasing popularity of 3D/VR/AR systems in various application domains requires development of efficient modelling methods and tools that are easy-to-use by domain experts who are not required to have technical skills in 3D modelling and programming.

The Semantic Web standards enable description of diverse types of web resources, including 3D content, with commonly used concepts. However, the use of semantic concepts may also facilitate the modelling of interactive 3D content.

The main contribution of this paper is a semantic mapping model for conceptual semantic representation of interactive 3D content. The proposed solution enables modelling of 3D content by non-IT professionals at an arbitrarily chosen (arbitrarily high)

This research work has been supported by the Polish National Science Centre Grant No. DEC-2012/07/B/ST6/01523.

level of semantic abstraction. The model leverages domain-specific ontologies, liberating domain experts from technical concerns that are typical for 3D content. The model is platform- and standard-independent, but it conceptually complies with well-established 3D content and semantic representation standards, facilitating widespread creation, dissemination, reuse and reasoning on 3D content in a variety of application domains.

The remainder of this paper is structured as follows. Section 2 provides an overview of the current state of the art in the domain of semantic description and semantic creation of 3D content. Section 3 contains a brief introduction to a method of semantic modelling of 3D content. Section 4 focuses on the new mapping model, which is a part of the modelling method. Section 5 presents an implementation of the proposed model. Section 6 discusses an example of the conceptual semantic design of a 3D room with a domain-specific ontology. Finally, Section 7 concludes the paper and indicates the possible directions of future research.

2 Related Works

In this section, Semantic Web technologies and methods of semantic creation of 3D scenes are considered.

2.1 Semantic Web

The primary technique for describing the semantics of web content is the Resource Description Framework (RDF) [1]—a standard devised by the W3C. RDF introduces basic means for making statements about resources. The RDF Schema (RDFS) [2] and the Web Ontology Language (OWL) [3] are W3C standards based on RDF, providing higher expressiveness for semantic descriptions of web resources. OWL defines a set of profiles, which differ in complexity and decidability [4]. The Semantic Web Rule Language (SWRL) [5] is an extension to OWL that permits semantic Horn-like rules. The Reaction Rule Markup Language (RuleML) [6] enables declarative description of reaction rules, in particular in the event-condition-action paradigm.

2.2 Semantic Creation of 3D Scenes

Several works have been devoted to semantic creation of 3D content. In [7], an approach to designing interoperable RDF-based Semantic Virtual Environments, with system-independent and machine-readable abstract descriptions has been presented. In [8], [9], [10], a rule-based framework using MPEG-7 has been proposed for the adaptation of 3D content, e.g., geometry and texture degradation, and filtering of objects. The content can be described with different encoding formats (in particular X3D), and it is annotated with an indexing model. In [11], the 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 detail.

In [12], a method of structured design of VR content has been proposed. In [13], [14], [15], an approach to generating virtual worlds upon mappings of domain ontologies to particular 3D content representation languages (e.g., X3D) has been considered. The following three content generation stages are distinguished: specification of a domain ontology, mapping of the domain ontology to a 3D content representation language, and generation of the final presentation. The solution stresses spatial relations (position and orientation) between objects in the scene.

Several works have been conducted on the modelling of behaviour of VR objects. In [16], the Beh-VR approach and the VR-BML language have been proposed for the creation of 3D content with behaviour (interactions and animations). The proposed solution aims at simplification of behaviour programming for non-IT professionals. Another method facilitating the modelling of content behaviour [17], [18], [19] provides a means of expressing primitive and complex behaviours as well as temporal operators. A tool-supported design approach to defining the behaviour of objects in X3D scenes has been presented in [20]. Finally, a rule-based ontology framework for feature modelling and consistency checking has been proposed in [21].

3 Overwiev of the Method of Semantic Modelling of 3D Content

Although several approaches have been proposed for conceptual creation of 3D scenes, they lack general solutions for semantic modelling of interactive 3D content, its components, properties and relations, at an arbitrarily chosen level of abstraction, by using various domain-specific ontologies.

The paper presents an outline of a method of semantic modelling of interactive 3D content with the focus on a mapping model of semantic domain-specific concepts to concrete semantic 3D content components and properties. In the presented method, modelling of 3D content may be performed at three distinct stages, which are partly dependent—design of concrete semantic 3D content components, mapping domain-specific concepts to the concrete semantic 3D content representation, and conceptual design of 3D content based on domain-specific concepts (Fig. 1). Every stage uses an appropriate semantic model.

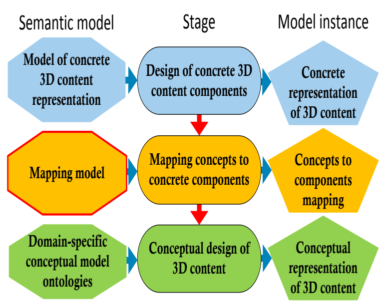

Fig. 1: Semantic modelling of 3D content

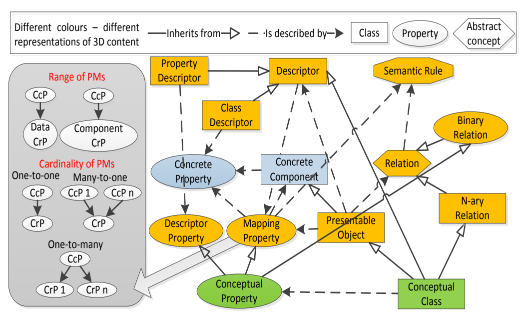

Fig. 2: Semantic mapping model for conceptual 3D content representation

At the first stage of modelling, a concrete representation of 3D content at a low level of abstraction and a high level of detail is created. The representation is created according to the multi-layered concrete model of interactive 3D content, which has been proposed in [22]. The model enables separation of concerns between six layers corresponding to distinct aspects of 3D content and different stages of 3D content design—*Geometry*, *Structure*, *Appearance*, *Scene*, *Logic* and *Behaviour* layers. The layers define concrete components (CrCs) and concrete properties (CrPs) that allow for describing different aspects of 3D content and which are common for well-established 3D content representation languages (e.g., VRML [23] or X3D [24]). The primary *Geometry Layer* introduces basic uniform individual geometrical CrCs and CrPs, e.g., lines, planes and meshes. The second *Structure Layer* introduces complex structural CrCs that assemble geometrical CrCs, enabling definition of spatial CrPs for them, e.g., position, orientation and size. The *Appearance Layer* adds appearance to geometrical and structural CrCs, e.g., colour, transparency and texture. The *Scene Layer* extends structural CrCs to navigable scenes with viewpoints. The *Logic* and *Behaviour* layers enrich CrCs that have been defined in the previous layers, with logic and behaviour, in particular animations and interactions. The layers are partly dependent—every layer uses only its concepts and concepts specified in its lower layers. Modelling of 3D content with the semantic model can be performed at any layer. For instance, design of a complex 3D scene with behaviour involves CrCs from all of the layers, while reusable 3D objects that are to be injected into different complex 3D scenes may be, e.g., only structural CrCs without appearance, thus designed at the *Structure Layer*.

The resulting concrete representation is a knowledge base compliant with the concrete model, which includes CrCs and CrPs corresponding to different layers of the content. Since the CrCs and CrPs cover aspects typical for 3D content, this stage of modelling is performed by a developer with technical skills in 3D modelling.

At the second stage of modelling, semantic domain-specific concepts that are defined in the selected domain-specific ontology, are mapped to the concrete 3D content representation created at the previous stage. The mapping is an ontology compliant with the mapping model, which will be discussed further. The mapping extends the domain-specific ontology with mapping concepts. Like the concrete representation, the mapping is created by a developer using a modelling tool – once for a particular domain-specific ontology, and it may be reused for representing various conceptual objects (CpOs) and conceptual properties (CpPs) that conform to this ontology.

At the last stage of modelling, conceptual semantic 3D content representation at an arbitrarily chosen (arbitrarily high) level of abstraction is created. The conceptual representation is a knowledge base compliant with the selected domain-specific ontology. The conceptual representation consists of conceptual objects (CpOs)—instances of domain-specific classes, which are described by conceptual (domain-specific) properties (CpPs). Complex CpOs, which include sub-CpOs, specify viewpoints and navigation modes, are referred to as scenes. The conceptual representation consists of CpOs and CpPs that are abstract in the sense of their final presentation as, in general, they could be presented in different manners (e.g., a 2D graphics, 3D model, voice, etc.). The representation may be created by a non IT-professional who has a knowledge of the domain-specific ontology selected for the modelling process. All conceptual representations, which are built upon common domain-specific ontologies, may reuse the same concrete representations and the same mappings, thus becoming presentable in three-dimensions.

The proposed approach has several important advantages in comparison to the available solutions for modelling of 3D content. First, the presented approach facilitates creation and analysis of 3D content at different levels of semantic abstraction. Second, the conformance to well-established Semantic Web standards and tools simplifies creation, dissemination and reuse of conceptual objects and scenes. It fosters the reuse of existing domain ontologies and knowledge bases. In addition, referring to the domain-specific meaning of particular 3D objects may improve creating, searching, exploring and reasoning on 3D content by domain experts who no longer need to go into details specific to diverse aspects of 3D content. Like in high-level (e.g., object-oriented) programming, the presented approach permits the creation of reusable CrCs and CpOs, which may be combined in different scenes. Next, the semantics of CrCs and CpOs can specify applicability and compatibility between different objects which are used in the designed content. Furthermore, 3D content described by the concrete semantic representation is platform and standard-independent, and it may be transformed to final 3D representations encoded in different languages, depending on particular requirements, e.g., the context of interaction, user location, preferences as well as hardware and software used.

4 Mapping Domain-specific Concepts to a Concrete Representation

Although high-level conceptual semantic description of virtual environments is sufficient for typical semantic processing and analysis, it must be extended to enable semantic representation of interactive 3D content. Such representation usually requires additional levels of detail that allow to accurately reflect the semantic concepts used by different components and properties of 3D content. For instance, stating that one car outruns another car is sufficient for a typical semantic analysis, but, to be presented, it requires an animation that changes the positions of both objects, which represent the cars.

In this section, a new semantic mapping model for conceptual representation of interactive 3D content is proposed. The model is an element of the semantic modelling method, which has been outlined in the previous section. The model enables mapping of domain-specific concepts to a concrete 3D content representation, thus permitting 3D content creation at an arbitrarily high level of abstraction.

The proposed mapping model (Fig. 2) links domain-specific concepts with CrCs and CrPs, which are a low-level detailed representation of these domain-specific concepts. To clearly separate the stages of mapping and conceptual design and to minimally affect the domain-specific concepts used, mapping concepts are created as super-concepts of domain-specific concepts and they indicate appropriate representational CrCs and CrPs. Domain-specific concepts hereby become mapping concepts, and individuals of domain-specific classes (CpOs) are individuals of mapping classes. Furthermore, statements made on a mapping concept are relevant to its domain-specific sub-concepts without introducing direct modifications of these domain-specific concepts. Such extension of the domain-specific ontologies does not affect the way in which conceptual design is performed by a domain expert, who does not need to take into account the low-level concrete representation of the domain-specific concepts used.

In the proposed approach, conceptual design of 3D content is based on CpOs, which are instances of domain-specific classes. CpOs may be described and linked by conceptual properties (CpPs). Mapping domain-specific concepts to CrCs and CrPs enables representation of CpOs and CpPs by combinations of these CrCs and CrPs. In this way, CpOs (instances of domain-specific classes) and their CpPs become presentable. The proposed model does not preclude representations of CpOs as combinations of other CpOs. Such representations can be defined during the conceptual design by typical means provided by the Semantic Web standards (such as combination by inheritance or restriction), thus they are not discussed in this paper. Mapping concepts that define complex dependencies are described with auxiliary *semantic rules* (SRs). Specifying representations for particular domain-specific concepts improves efficient modelling and reusability of these concepts in contrast to defining individual representations for particular CpOs. A CpO in the modelled content has all of the presentational effects of its classes and super-classes.

The modelled 3D content is semantically complete in the sense that no semantic concepts or individuals are added or removed during its presentation – neither in the conceptual nor in the concrete representation, only the values of individual properties may change. For instance, the motion of an object may be stopped by turning off its animation, but not by removing the animation property.

The introduced mapping concepts may form hierarchical structures with multiple inheritance. The 3D representation of a descendant concept extends (and not restricts) the representations (sets of presentational effects) of its parent concepts with additional presentational effects. Presentational effects implied by descendant concepts take precedence over the effects of their parent concepts. For example, objects made of silver may have the same reflectiveness but different colours than other metal objects.

While the semantic representations of static 3D content (without logic and behaviour) are in general decidable, introducing complex descriptions of logic and behaviour can make them undecidable, which affects possible reasoning on the semantic representations but still enables proper presentation of the content.

The following sections explain the details of the proposed mapping model with the taxonomy and semantics of its particular entities. Since the introduced mapping concepts are ascendants of domain-specific concepts, the presented discussion is also relevant to these domain-specific concepts.

4.1 Presentable Objects

A *presentable object* (PO) is the primary entity of a conceptual semantic representation of 3D content. Every class from a domain-specific ontology, whose instances need to have individual representations in the created 3D content, must be specified as a sub-class of a PO class. Each PO class is a sub-class of the *geometrical component* or the *structural component* class of the multi-layered 3D content model. During the design of CrCs, a developer may arbitrarily extend PO classes by determining various CrPs to represent the geometry, structure, space, appearance, logic or behaviour of POs, thus making their child domain-specific classes also sub-classes of the *geometrical*, *structural*, *spatial*, *appearance*, *logical* or *behavioural component* classes of the concrete representation model. As the CrPs concern specific aspects related to 3D content, they are not intended to be manipulated by a domain expert (a non-IT professional) during the conceptual design. Therefore, only CrPs that are common for different instances of POs should be specified as such inherent properties of their PO class, e.g., accurate reusable models of plants and chemical compounds may be reused in different contexts always with the same values of properties. Properties of the concrete model that often need to be differentiated for different POs are specified using other concepts of the proposed mapping model.

During the conceptual design, POs in the content may be described with the other mapping concepts of the proposed model—*mapping properties*, *descriptors* and *rela-*

tions. In contrast to POs, the remaining concepts reflect aspects of 3D content that have no individual representations in the final 3D scene.

4.2 Properties of Presentable Objects

In the proposed semantic model, POs may be described by *mapping properties* (MPs). Each MP is a super-property of some CpPs and it links them to representational CrPs. The values of representational CrPs are functions of the values of their primary MP, e.g., the RGB triple '1 0 0' corresponds to the 'red' colour. Depending on the complexity of the concrete representation of an MPs, complex MPs may require auxiliary SRs, which determine the values of the representational CrPs upon the values of these MPs. The value of each MP is a literal of a simple data type (e.g., integer, string or date).

Different categories of *property mappings* (PMs) are distinguished with regards to the range of representational CrPs as well as the cardinality of PMs. These two groups are mutually independent, as each PM belongs to both of them.

Range of Property Mappings. Two types of PMs are distinguished in the proposed model in terms of the range of the representational CrPs that are used in the mapping—*data* PM and *component* PM. A *data* PM links CpPs to CrPs whose ranges are literals of a simple data type (e.g., integer, string, date, etc.). A *component* PM links CpPs to CrPs whose ranges are CrCs. *Component* PMs enable describing features of POs that cannot be sufficiently described by *data* PM. For instance, a 3D object moving on a surface is connected to a CrC that reflects the animation and specifies a set of necessary values, such as time, speed, recurrence, etc. A *component* PM requires an auxiliary SR determining appropriate CrPs of the associated CrC with regard to the primary CpP. Each *combined* PM is a combination of *data* and *component* PMs.

Cardinality of Property Mappings. The cardinality of links in a particular PM determines the numbers of CpPs and CrPs that are used in the PM. Three types of PMs are distinguished. A *one-to-one* PM links a single CpP to a single CrP. This category of PMs is convenient for CpPs whose concrete representations depend only on the values of these CpPs, and not on any other CpPs of the described PO, and vice versa—these CpPs do not influence any other CrPs. *One-to-one* PMs are sufficient for determining independent features of POs, e.g., colour, pattern, size, etc. A *one-to-one equivalent* PM is the simplest PM, which copies the value of the primary CpP to the CrP (e.g., a direct RGB colour description).

A *many-to-one* PM links a number of CpPs to a single CrPs. This category of PMs is convenient for CrPs whose values are determined by a number of CpPs. *Many-to-one* PMs are used for describing advanced and relative features, e.g., the colour of an object may be determined by both its material and temperature. *Many-to-one* PMs have more complex descriptions than *one-to-one* PMs and they require additional auxiliary SRs that determine the exact aggregated value of the CrP by linking this value to the different associated CpPs.

A *one-to-many* PM links a single CpP to a number of CrPs. The CpP aggregates the semantics of multiple associated CrPs. *One-to-many* PMs are convenient for conceptual semantic description on a high level of abstraction that hides the details of the low-level concrete representation and aggregates multiple low-level CrPs. For instance, a PO made of gold is yellow, not transparent and it reflects light. *One-to-many* PMs require

SRs for determining the values of the CrPs upon the primary CpP value. A *many-to-many* PM is a combination of the previous categories of PMs.

4.3 Descriptors of Presentable Objects

In some cases, MPs are not sufficient for semantic modelling of 3D content when POs need to be described by domain-specific concepts that gather multiple domain-specific CpPs and that need to be defined and be legible in detail to a modelling user. Such a requirement is not satisfied by MPs that use *one-to-many* PMs, which aggregate multiple CrPs of the concrete model by SRs. SRs are specified in the concrete representation by a developer, and thus they are hidden to a user modelling on the conceptual level.

Semantic *descriptors* are a functional extension of *one-to-many* PMs, which are used for describing POs. A *descriptor* determines an arbitrary set of CrPs or CpPs. Although these properties are associated with the *descriptor*, they describe the PO that the *descriptor* is applied to, i.e. the *descriptor* only carriers the properties. Two types of *descriptors* are distinguished.

Class Descriptors. A *class descriptor* (CD) is a class, for which a set of CrPs is specified. A CD may be used as a super-class for arbitrarily selected PO classes, or as a class for arbitrarily selected POs. Unlike PO classes, CDs are not used to create independent 3D objects existing within a scene. Instead, they are used to enrich POs with additional CrPs that cannot be defined inherently for a particular PO class, because they need to be assigned selectively only to some instances of PO classes. For example, a class of interactive rotating POs includes only selected POs that rotate after being touched. The CrPs of a CD are not modified during the conceptual design.

Property Descriptors. A *property descriptor* (PD) is a semantic individual that determines a set of MPs. A PD is connected to the described PO by a *descriptor property*. Although a PD may be described by numerous MPs, these MPs are related to the described PO. For example, furniture can be made of different types of wood, each of which is described by a few properties such as colour, shininess, texture, etc. These MPs need to be specified by a domain expert individually for different pieces of furniture. The MPs of a PD may be modified during the conceptual design.

4.4 Relations of Presentable Objects

The proposed model provides *relations* (RLs) to permit semantic modelling of dependencies between POs. Every RL has at least two parts (participants), which are connected to one another by mutual dependencies related to some aspects of 3D content—geometry, structure, space, appearance, logic or behaviour—reflected by CrPs. In each RL, at least one part affects other parts and at least one part is affected by other parts, and each part is either affecting or affected. In the concrete representation of an RL, CrPs of at least a single PO depend on CrPs of at least one another PO.

Cardinality of Relations. In terms of cardinality, *binary* RLs and *n-ary* RLs are distinguished. A *binary* RL links two POs and it is represented with an auxiliary SR that subordinates selected CrPs of the affected part with selected CrPs of the affecting part. In *uni-directional* RLs one part is affecting and the other one is affected. For instance, an object (affected part) that is placed on a table (affecting part) takes its height as one of the position coordinates without changing any properties of the table. In *bi-directional*

RLs both parts are affecting and affected. For example, a bullet hitting a wall breaks up and partly damages the wall.

In contrast to *binary* RLs, *n-ary* RLs allow for modelling complex dependencies between a number of POs, e.g., an RL that defines the relative position between three objects does not only indicate these POs, but also specifies their relative orientations and distances between them.

Presentational Variants of Relations. The use of auxiliary SRs in RLs does not only allow for describing a mutual influence of parts of RLs, but also provides the possibility to distinguish different *presentational variants* of the modelled RLs (presentational polymorphism of semantic RLs). While the semantics of an RL remains the same (what is important when searching, exploring and reasoning on the scene in the typical semantic manner) and it is not desirable to distinguish different semantic sub-RLs, its 3D representations may be different depending on, e.g., types of the described parts or their properties. For instance, sitting on a sofa differs from sitting on a floor. Moreover, different subjects sit in different manners, e.g., a dog or a human. While the 'sitting' RL remains the same for different semantic analyses, it requires different final 3D representations, depending on the parts of the RL.

5 Implementation of the Proposed Mapping Model

The proposed mapping model for conceptual representation of 3D content can be implemented as an ontology with the well-established Semantic Web technologies (RDF [1], RDFS [2], OWL [3] and Reaction RuleML [6]). The implementation of the particular concepts of the model is explained below.

Each PO class is an `owl:Class`. It may become a super-class of any class of a domain-specific ontology, whose individuals need to have independent representations in the final 3D scene. Properties which are inextricably connected to all POs of a particular PO class, are specified using the `owl:hasValue` and the `owl:someValuesFrom` restrictions on the level of the definition of this PO class.

Each MP is an `owl:DatatypeProperty` supported by an auxiliary RuleML semantic `Rule`. The `rdfs:domain` of an MP indicates the appropriate domain classes, its `rdfs:range`—the acceptable data types. *One-to-one equivalent* PMs are implemented by the `owl:equivalentProperty`.

Each CD is an `owl:Class` with `owl:hasValue` restrictions indicating the desirable values of particular CrPs, which are gathered by the CD. Each PD class is an `owl:Class` with `owl:someValuesFrom` restrictions. Each *descriptor property* is an `owl:ObjectProperty` with an `rdfs:domain` and an `rdfs:range` set to the described PO classes and the describing PD class respectively.

Each *binary* RL is an `owl:ObjectProperty` supported by RuleML `Rules`. The `rdfs:domain` and the `rdfs:range` of a *binary* RL indicate the parts of the RL. Each *n-ary* RL is an `owl:Class` whose individuals determine the parts of the *n-ary* RL and its desirable CrPs.

Inheritance of the mapping concepts is implemented with `rdfs:subClassOf` property (for PO classes, descriptors and n-ary RLs) and `rdfs:subPropertyOf` (for MPs, *descriptor properties* and *binary* RLs).

Due to the restrictions on class members, which are used for POs and CDs, at least the expressiveness of the OWL EL or OWL RL profiles is required for the proposed model. Hence, in general, the semantic representations of static 3D objects and static 3D scenes (without logic and behaviour) are decidable with the polynomial combined complexity for the majority of reasoning problems [4]. The representations of dynamic 3D content (with logic and behaviour) are undecidable because of the use of SRs [5]. Although, in general, the undecidability makes it impossible to find solutions for some queries against the semantic representations of 3D content, the gain achieved by logic and behaviour description is more important for efficient modelling of complex 3D content.

6 Example Conceptual Design of an Interactive 3D Scene

In this section, an example of conceptual semantic design is presented to demonstrate the main benefit of the semantic representation model proposed—an easy-to-use method of modelling 3D content by non IT-professionals. The example scene presents a room, e.g., for e-commerce flat presentation or design systems. The two other stages of the semantic modelling of 3D content—the design of concrete 3D content components and mapping concepts to the concrete representation—are, in general, rather complex processes, which are typically performed once by a developer for a particular set of domain-specific ontologies. These processes have been outlined in Section 3, and they are not considered in this example.

A conceptual scene description encoded by a non-IT professional is presented in Listing 1 (the RDF-Turtle format). Its final 3D representation is presented in Fig. 3[1]. Since the scene is a knowledge base, which can be based on a domain-specific ontology, it can be built with any semantic modelling tool (e.g., Protégé). Since the scene is abstract in the sense of its final presentation, it does not cover any aspects that are directly related to 3D content. Such aspects are addresses by a developer during the design of concrete 3D content components.

Lines 1-8 form the scene (a room) and POs, which are incorporated in it. It is assumed that the mapping has already been performed for the scene and it introduces mapping concepts, which are super-concepts of the domain-specific concepts, so the discussion of this example concerns the mapping concepts instead of their domain-specific descendants. The MPs indicate materials that the `table` and the `decoration` are made of (9,10). The `isMadeOf` MP uses a *one-to-many* PM, as it determines the texture or the colour of the PO and its reflectiveness. The `RotatingObject` CD assigned to the `tableFlowerpot` (11) enables a single rotation of the flowerpot after touching it. The `chairAppearance` PD (12-15) specifies the `shininess` and the `material` of the `chair`, which may be managed by a domain expert.

To enable placing furniture in the room, a reference surface must be given (a floor—16). The `standsInTheMiddleOf` *binary* RL places the table in the middle of the floor respecting its size (17). The `tableFlowerpot` and the `decoration` may be placed in an arbitrary point on the `table`, as they are described by the generalized `standsOn` *binary* RL (19,20), which is an ascendant RL of the `standsInTheMiddleOf`. Both flowerpots in the scene stand on some furniture (they are in the same

[1] In the final 3D presentation of the scene, the 3D models of
a table (http://resources.blogscopia.com/2011/05/19/bar-table-and-chairs/),
a chair (http://resources.blogscopia.com/2010/05/11/armchair-2-download/) and
a flowerpot (http://resources.blogscopia.com/2010/04/22/flowerpot/) have been used.

type of RL with different POs—18,19), but the visual presentations are different in these two cases. The `chairFlowerpot` tilts the soft surface of the `flowerpotChair`, while the `tableFlowerpot` does not affect the hard surface of the `table`. The relative position of the chairs is described by the `distance`, which is set to 10 units in the n-ary `chairRelativePosition` RL (21).

In the presented example, the transformation of the conceptual scene representation to its final 3D representation encoded in VRML has been performed manually. However, the development of a tool for automatic semantic transformations is planned. The conceptual representation presented in Listing 1 includes 15 times less characters than its final equivalent. The presented solution enables creating representations of 3D content that are much more concise than representations encoded in typical 3D content representation languages.

```
1:  room rdf:type Room.
2:  floor rdf:type Floor.
3:  table rdf:type Table.
4:  chair rdf:type Chair.
5:  flowerpotChair rdf:type Chair.
6:  tableFlowerpot rdf:type Flowerpot.
7:  chairFlowerpot rdf:type Flowerpot.
8:  decoration rdf:type Decoration.
9:  table isMadeOf "wood".
10: decoration isMadeOf "metal".
11: tableFlowerpot rdf:type
     RotatingObject.
12: chairAppearance rdf:type
     AppearanceDescriptor.
13: chair appearance chairAppearance.
14: chairAppearance shininess "0.5␣0.4␣
     0.3".
15: chairAppearance material "leather".
16: room hasFloor floor.
17: table standsInTheMiddleOf room.
18: chairFlowerpot standsOn
     flowerpotChair.
19: tableFlowerpot standsOn table.
20: decoration standsOn table.
21: chairRelativePosition hasPart chair,
       flowerpotChair ; distance "10".
```

Listing 1: A conceptual semantic representation of a 3D scene

Fig. 3: A final 3D representation of the scene

7 Conclusions and Future Works

In this paper, a new mapping model for conceptual semantic representation of 3D content has been proposed. The proposed approach leverages the existing Semantic Web standards to enable modelling of 3D content by non-IT professionals at an arbitrarily chosen level of abstraction, using domain-specific ontologies and knowledge bases. The proposed approach may simplify 3D content creation, dissemination and reuse in multiple application domains, such as building commercial and museum 3D exhibitions, games and advanced business presentations.

The proposed mapping model has some limitations. First, it is inconvenient for conceptual representations of simple 3D objects and scenes that are neither reused nor shared, and that are accessed by authors (who know their semantics). In such cases, referring to the high-level semantics of the modelled content is not necessary. Second, designing 3D content with the presented approach requires explicit specification of all of the objects and their properties that need to be presented in the resulting scene. Methods of dynamic semantic composition of 3D content can be proposed to permit implicit conditional query-based assembly of 3D scenes from different reusable components.

A modelling tool supporting the proposed model is planned to be developed. Then performance metrics will be calculated and the model will be validated and evaluated in terms of the efficiency of 3D content creation and encoding. Modelling 3D content by a group of users can allow to verify the approach and to compare the times required for 3D content creation to the times obtained with widely used modelling tools, such as 3ds Max or Blender. The sizes of documents describing conceptual 3D content representations can be compared to equivalent representations encoded in well-established 3D content representation and programming languages, such as X3D or ActionScript.

Other possible directions of future research incorporate several facets. First, automatic transformation of conceptual representations to final 3D content representations encoded in different languages should be implemented. Second, the presented example of semantic modelling assumes a uni-directional transformation of a conceptual scene to a final 3D scene. To permit semantic management and exploration of 3D content in real-time, a persistent link between the primary conceptual objects and the components of the final generated 3D content should be maintained. Third, an additional means can be proposed to represent descriptors that determine the order of the semantic properties included. For instance, the 3D representation of a rotating object that moves may differ from the 3D representation of a moving object that rotates. Finally, the context of user–system interaction (e.g., user location, preferences, client device, etc.) can be considered to enable multi-platform presentations of semantic 3D content on a multitude of available mobile and desktop devices.

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