Bridging Semantic Web and Digital Shapes

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Abstract

Since the volume of multimedia content available on the Web is continuously increasing, a clear need for advanced techniques capable of performing an effective retrieval and management of such data. In this context, in order to reason on digital shapes and their associated semantic, we see a growing interest in exploiting the potential of the Semantic Web in different research fields. We present here the design and initial development of our new system, that we call `be-SMART` *for inspecting digital 3D shapes by extracting geometrical and topological information from them and for structuring and annotating these shapes using ontology-driven metadata. We describe the general structure of the system, its modules and their mutual relations. We also provide motivations for further work in developing new techniques for managing 3D models on the Web.*

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computational Geometry and Object Modeling]: I.3.8 [Applications]: I.3.2 [Stand-alone systems]: I.3.m [Miscellaneous]:

1. Introduction

With the advent of the Semantic Web [BLHL01], there has been a research focus, both commercially and in the academia, in the development of techniques to annotate multimedia content on the Web, using Web ontology languages such as RDFS [BG00] and OWL [BvHI*03]. As pointed out in [aim07, HWGS*06], at this stage of research infrastructures development, there is a general request of tools able to extract semantics from multimedia content (e.g., automatic or semi-automatic annotation tools), and to enhance digital representations with context-dependent metadata. This leads to the need for a strong integration of Semantic Web technologies in different research fields operating on multimedia content, as for example computer graphics and scientific visualization. Given semantically rich metadata, collections of heterogeneous multimedia (e.g., images, surface meshes, volume meshes) can be more accurately searched and browsed, with new knowledge derived from existing annotations [HWGS*06].

In the near future, we foresee the need of systems capable of exploring, organizing and understanding digital shapes. The purpose can be also to automatically populate repositories with complete and well-detailed metadata for digital models, improving in this way scientific communication and supporting the generation of new knowledge, specifically about 3D objects what complex geometric and topological structure.

The most common and simple representation for a 3D object consists of a mesh of triangles joining the points belonging to the object boundary. 3D object models have a richer content of information with respect to 2D images, as for example geometrical and topological information. Beyond geometry and topology, there is no semantics associated with the 3D object by default. Therefore, 3D models must be analyzed and successively semantically annotated, improving the expressiveness of their representations. All the extracted knowledge can be represented formally and methodically in an ontology, which is able to provide different levels of abstraction and which is able to ensure capability of reasoning on an object and of inferring implicit information. Several complex steps are required to create and associate semantics with a multimedia object. Some of such steps are necessarily context-dependent. Semantic can have different levels of abstraction and the knowledge associated with a 3D model is generally not linear but structured in a multifaceted model. In any case, geometric and topological information can be helpful for reasoning on a 3D model in almost all application domains it can be used.

This work presents part of our research activity which is leading to the development of *be-SMART* (*BEyond Shape*

Modeling for understAnding Real world represenTations), a system for geometric-topological inspection and semantic annotation and structuring of digital shapes. Specifically, we focus on the description of the overall system structure and the different modules identified which, as first step, perform topological inspection of a 3D shape and decompose such shape into meaningful parts according to topological criteria. After this analysis, the system will semantically annotate the 3D model according to ontology-driven metadata defined in [AMH*05].
The remainder of this paper is organized as follows. In Section 2, we present the general structure of *be-SMART*, outlining the different modules and their relations, in Section 3 we sketch the ongoing implementation. Finally, in Section 4, concluding remarks are drawn and future developments are discussed.

2. The Design of *be-SMART*

In the last years, a general trend within computer graphics research community goes in the direction of improving the quality of the intercommunication using the Web as a basic tool. This leads to a need for strong integration of Knowledge Management technologies in Computer Graphics in order to make the knowledge embedded in digital models explicit and sharable [RRTS02, aim07].

be-SMART is designed to be a system for geometric-topological inspection and semantic annotation and structuring of 3D shapes. It relies on the general idea to automatically extract information about features and regions of interest and to provide an intuitive interface to researchers in order to easily understand digital models. *be-SMART* aims at calculating quantitatively replicable geometric and topological data and at generating ontology-driven metadata about an object. It aims at:

- *extracting* (automatically) geometric and topological information from a given digital shape and at maintaining them using ontology-driven metadata;
- *annotating* digital shapes (both manually and/or automatically) using editing technologies and context-dependent segmentation techniques;
- *structuring* and *idealizing* (automatically) the shape on the basis of the obtained segmentation, in order to create an iconic representation and a structural multi-level representation of the initial shape guided by the associated semantic.

The system could be coupled with a semantic web portal, which provides digital shapes metadata management and interaction functionalities, as, for example, [MIN07, dsw07].

be-SMART has been designed to be a Java-based, platform independent, multimedia content structuring and annotation system, which uses an ontology to provide the expressiveness required to assert the contents of digital data, as well as information about the digital media itself (date of creation, upload person, etc.). Extending the idea of PhotoStuff [HWSG*05], *be-SMART* will allow users to annotate regions of a 3D model with respect to concepts in any ontology specified in RDFS or OWL. Since it allows dealing with 3D shapes, the system uses plug-ins and libraries for visualizing and modifying a 3D model through the use of advanced and innovative technologies (Xj3D, X3D) [xj3, x3d]. The general idea is that an X3D file, representing the initial 3D model, is successively modified and transformed (by the use of ad-hoc XSLT transformations) according to the information extracted automatically as well as to the segmentations performed (either manually, or automatically). In the transformation process, new tags will be added dynamically to the X3D file in such a way that, at the final stage, all geometric, topological and semantic information will be maintained, and the final model will preserve the knowledge acquired and/or extracted during the different processing steps. Such information will be maintained in separate RDF files suitably linked with the initial X3D file.

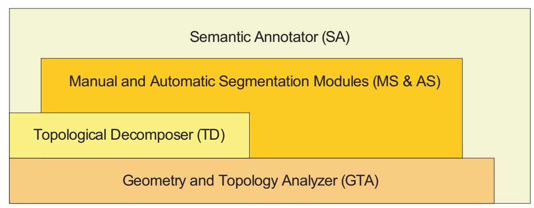

Figure 1: *The general business logic of be-SMART system. Five different modules have been defined and they are organized at different levels of abstraction. The two modules at the bottom are the ones described here. They are application independent. All the other modules are context-dependent and for each of them, ad-hoc heuristics and semantics must be developed.*

be-SMART is designed to be a modular and platform independent system. This means that the different modules collaborate in the creation of the final annotated digital model following specific ontology-driven processes. We list here the modules we have defined (a schema of the system is depicted in Figure 1):

1. *Geometry and Topology Analyzer (GTA)*: it analyses the input and extracts geometrical/topological information which are successively maintained in the enriched model and/or as instance values of a given ontology.
2. *Topological Decomposer (TD)*: starting from the information extracted with the *GTA* this module produces a graph-based representation of the model, the *Decomposition Graph*, which groups geometric components (namely, vertices, edges and triangles) and associated to each group context-independent semantic meaning.
3. *Manual Segmentation module (MS)*: This module offers both simple and advanced editing functionalities allowing the user to select portions of the mesh and to annotate

them according to a given context-dependent ontology. The produced segmentation is maintained in the *Decomposition Graph*.

4. *Automatic Segmentation module (AS)*: This module offers the possibility to apply different segmentation algorithms for decomposing the model into meaningful parts (according to some context-dependent criteria). The produced segmentation is maintained in the *Decomposition Graph*.
5. *Semantic Annotator (SA)*: This module offers the capabilities of associating specific metadata values to specific portions of the model according to pre-loaded ontologies. This means that the tool associated metadata to nodes of the *Decomposition Graph* representing the model.

Among them, the first two modules have been already implemented. The first module, the *Geometry and Topology Analyzer*, extracts the topological characteristics of the initial digital model through its mesh-based discretization. All the extracted characteristics (e.g. the number of triangles, edges, wire- edges and vertices or the number of non-manifold vertices and non-manifold edges) are successively attached to the model to enhance its representation. The module is based on a representation of the underlying simplicial mesh as a Triangle-Segment (TS) data structure [DMPS04]. The properties extracted by the *GTA* are successively mapped into the metadata identified for the concept *NonManifoldMesh* in the Common Shape Ontology designed within [aim07] and described in [AMH*05].

The second module, the *Topological Decomposer*, is mainly focused on the construction of a graph-based representation of the model, that we called the *Decomposition Graph*, which captures complexity of the connectivity among the meaningful parts of the model identified by the *GTA*, namely *wire-webs* (maximal 0-connected sub-meshes of the mesh consisting only of wire edges), *sheets* (maximal 1-connected sub-meshes of triangles which do not bound a void) and *shells* (any maximal 1-connected sub-meshes enclosing voids and not containing triangles dangling at non-manifold edges). The *Decomposition Graph* defines a decomposition of the input shape into a collection of components of uniform dimension and it supports the extraction of global topological features of the decomposed shape (see also [DH07b, DH07a]). The *Decomposition Graph* is a hypergraph $H =< N,A >$ in which the nodes in N correspond to the components of the decomposition (namely wire-webs, sheets and shells), and the hyperarcs in A capture the structure of the connectivity among these components.

3. Development of *be-SMART*

be-SMART is a complex system, modular and extensible which, as final goal, will support researchers working in the wide field of Computer Graphics and Computer Vision. Experts will be guided to reason on digital shapes and they will be able to improve their knowledge on the data available on the net. The structuring of the information as well as the reasoning on structured data will be ontology-driven allowing to infer implicit information and potentially to extract new knowledge from the data. The system is at step two of five of its development, and the modules involved are complex. Some functionalities have to be implemented ex-novo, some others can be inherited by existing Semantic Web tools. In particular, *be-SMART* has been inspired by PhotoStuff, which is a Semantic Web image annotation tool using an ontology to maintain information of an image [HWSG*05]. PhotoStuff allows users to annotate regions of an image with respect to concepts in any ontology specified in RDFS or OWL. PhotoStuff is designed to load multiple ontologies at once, enabling a user to markup images with concepts distributed across any of the loaded ontologies. We are currently working on the integration of PhotoStuff functionalities to be-SMART.

For the *Automatic* and *Manual Segmentation Modules* (*AS* and *MS*), we are working on them so that they will perform segmentations of the initial model on the basis of context-dependent heuristics. If the initial model is non-manifold, the two modules will take advantage of the *Decomposition Graph* produced by the *TD* and eventually they will perform the segmentation only on the manifold parts in which the model has been initially decomposed. Both the *MS* and the *AS* will rely on the idea that, once the model has been segmented, they both will update (or build) the *Decomposition Graph*. This graph will be successively passed to the *Semantic Annotator (SA)* module so that the user will be able to add semantic meaning to each identified portion of the model according to the expert knowledge possibly maintained in specific context-dependent ontologies.

4. Concluding Remarks and Future Work

In the last years, 3D objects have become widely available on the net and they are used in many disciplines in academia and industry. The general trend goes now towards the organization of multimedia content into digital libraries, and attention has turned towards archiving 3D objects in an intelligent way e.g. [RRTS02, aim07, MIN07]. This means also that it is important to extract and maintain that knowledge embedded in a digital shape which cannot be simply identified and that strongly depends on the specific application domain.

We have presented here part of our research activity which leads to the development of *be-SMART* a system for geometric-topological inspection and semantic annotation and structuring of digital shapes. The main objectives of *be-SMART* are the automatic extraction of features and regions of interest, the computation of quantifiable, replicable geometric and topological data, and the generation of ontology-driven metadata about the object under study. We outlined here the general structure of the system and its modules. The first two have been already implemented and they perform the extraction of geometrical and topological information from 3D shape models and on the successive decomposition of those models which are non-manifold into manifold parts. The connectivity among the identified portions of the model is maintained in what we called the *Decomposition Graph*. This graph will be used also by the *Manual* and *Automatic Segmentation Modules*.

In our current and future work, we are going to integrate in the system different segmentation procedures in order to implement the third module, and we will develop a user-friendly interface to allow editing and manual on-the-fly segmentation of the models. The last steps will be designing and implementing the iconization module. We are going also to take into consideration proposal for web standards such as the one in [PF06] where the authors propose a solution that allows to attach semantic information to X3D using RDF and the semantic framework for the management of 3D data proposed in [BGVOM06]. This will be done in order to assure a good design and structuring of the overall system and to clarify how the data could be further used from external modules. We believe that *be-SMART* will have great impact among the researchers in both Computer Graphics and Computer Vision research communities and that it will be an important step towards an actual use of the Semantic Web for multimedia content.

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