Eurographics Italian Chapter Conference (2007)
Raffaele De Amicis and Giuseppe Conti (Editors)

Bringing the Semantics into Digital Shapes: the AIM@SHAPE Approach

Bianca Falcidieno

Coordinator of the Network of Excellence AIM@SHAPE (EU-FP6 Contract n. 506766)
IMATI -CNR, Genova, Italy
bianca@ge.imati.cnr.it

Abstract

This presentation describes the main objectives and achievements of the European Network of Excellence AIM@SHAPE. This NoE is aimed to advance research in the direction of semantic-based shape representations and tools able to acquire, build, transmit and process shapes with their associated knowledge.
Acting on a multi-disciplinary research field, AIM@SHAPE deeply integrates geometry processing, computer graphics and vision with knowledge technologies. The core of the integration resides in the homogenisation of the approach to modelling shapes and their associated semantics using knowledge formalisation mechanisms: meta-data and ontology. A main objective is also to develop an innovative e-science platform for modelling, processing and sharing digital shapes, called the Digital Shape Workbench (DSW). Through the definition of general and specific shape ontologies, the DSW is a framework able to store shapes, tools, and publications along with the knowledge related to them.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Line and Curve Generation

1. Introduction

In the last decade, the concept of multimedia has evolved from single-content type, mainly related to non-textual data (e.g., images, videos or audio), to truly multimedia content which integrates multiple medium types. Research on multimedia, however, is largely devoted to content whose digital representation is at most two-dimensional (e.g., images), possibly with the addition of time and audio (e.g., videos). At the same time, Computer Graphics has reached quite a mature stage where fundamental problems related to the modelling, manipulation and visualization of static and dynamic 3D shapes are well understood and solved. Considering that most PCs connected to the Internet are now equipped with high-performance 3D graphics hardware, it seems clear that in the near future 3D data will represent a huge amount of traffic and data stored and transmitted using Internet technologies. It has been predicted that "*geometry is poised to become the fourth wave of digital-multimedia communication*", where the first three waves were sounds in the 70's, images in the 80's, and videos in the 90's.

There is a phenomenal activity around digital shapes. Currently in widespread use for computer-aided design and manufacture, they are becoming crucial to genomic, proteomic and medical modelling. In areas like culture, education and entertainment, shapes are equally essential in developing convincing virtual worlds. They are used extensively to develop models and create simulations, and to devise new designs that conform to engineering constraints, yet remaining functional and aesthetically pleasing. In personal entertainment, it is possible already today to buy your own 3D character for some computer games.

If most of the efforts in multimedia are currently focused on solving problems related to image-oriented content, the next step is to add a new dimension, i.e. 3D or time varying 3D, to this content and endow it with semantics. The impact of 3D content is comparable to the one of images, with a number of distinctive properties. 3D shapes offer

© The Eurographics Association 2007.

delivered by
EUROGRAPHICS DIGITAL LIBRARY
www.eg.org diglib.eg.org

more potential for interactivity since they can be observed and manipulated from different viewpoints. Also, the richness of their representation potentially contains more knowledge about an object than a simple picture. At the same time, representing a complex shape is known to be highly non trivial, due to the sheer mass of information involved and the complexity of the knowledge a shape can reveal. Therefore, we need tools for making digital shapes machine-understandable and not just human-understandable as today, developing semantic mark-up of content, intelligent agents and ontology infrastructures for fully-3D content.

2. The AIM@SHAPE Vision and Mission

In this context, the FP6-IST Network of Excellence AIM@SHAPE is pursuing the introduction of knowledge management techniques in shape modelling, with the aim of making explicit and sharable the knowledge embedded in multi-dimensional media, with focus on 3D content. On the one hand, this requires the development of tools able to extract semantics from 3D models (e.g. automatic or semi-automatic annotation tools), on the other hand it is necessary to build a common framework for reasoning, searching and interacting with the semantic content related to the knowledge domain. One of the objectives of AIM@SHAPE is therefore to develop new methods and tools for modelling, extracting and reasoning about knowledge related to digital 3D content, where knowledge is concerned with *geometry* (the spatial extent of objects), *structure* (object features and part-whole decomposition), *attributes* (colours, textures, names attached to an object, its parts and/or its features), *semantics* (meaning or purpose in a specific context), and has interaction with *time* (e.g., shape morphing, animation, videos).

An example of semantics-based shape modelling is illustrated in Figure 1, where a bottom-up pipeline for modelling a virtual human is shown. The modelling process starts with the scanning of a real body model (a), and the acquired data are used to build a first digital model of the real shape (b). The geometry of the body is represented in this case by a triangle mesh, which contains all data needed to render nicely the digital object. In the triangle mesh, however, nothing is stored about the semantics of the objects or of its features: it is not possible to distinguish points belonging to the legs from points belonging to the hands. With suitable shape analysis methods, it is possible to detect relevant parts of the digital model, having a protrusion-like form (c); based on this analysis the initial geometry is segmented and the triangles are organized in a skeleton-like structure of the body model (d). Finally, another step of analysis is used, which makes use of context-specific rules, to tag parts of the structure with semantically-oriented labels, such as legs, arms and so on. The tagged model is now ready for being animated properly in a virtual environment scenario (e).

The shift from a purely geometric to a semantic-aware level of 3D content production and storage requires fundamental research to be done within an underlying common conceptualisation framework, which formalizes shape knowledge via the adoption of shared metadata and ontologies.

The AIM@SHAPE project integrates research of 13 institutions (see Section 5) aiming at representing and processing knowledge related to shapes. The mission of AIM@SHAPE is to advance research in the direction of semantic-based shape representations and semantic-oriented tools to acquire, build, transmit and process shapes with their associated knowledge. The multi-disciplinary field created by this project deeply integrates geometry processing, computer graphics and computer vision with knowledge technologies.

3. The AIM@SHAPE Results

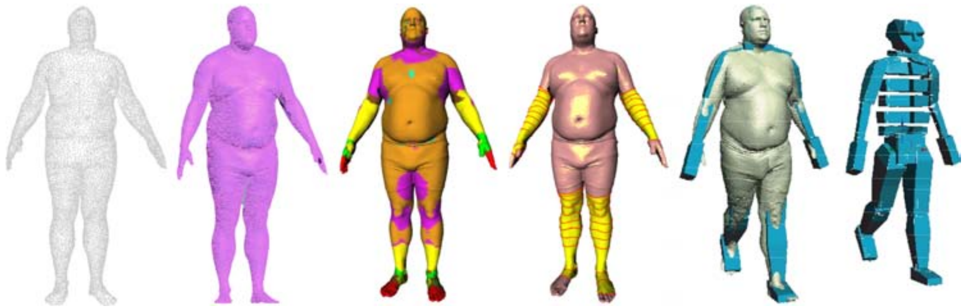
From this point of view, the main objective of AIM@SHAPE is the development of an e-science platform for modelling, processing and sharing multi-dimensional media, called the Digital Shape Workbench (DSW), which is an elaborated framework to store shapes, tools, and publications along with the knowledge related to them and expressed through the definition of general and specific shape ontologies.

3.1. Ontology Design

In AIM@SHAPE, *ontologies* are structured frameworks of concepts, meanings and relations which make explicit the knowledge associated with shapes (for example, see Figure 2). They predefine semantics that can be used to annotate shapes with domain-specific information. As the project is concerned with the association of semantics and shapes, the design of ontologies is a fundamental activity. When shape knowledge is organized according to a specific ontology, it can be directly used by computer applications that relate to that ontology's application domain, for instance a *search engine*. On the human level, ontologies facilitate communication by making explicit and clear what a specific term refers to. Within AIM@SHAPE, five ontologies have been defined, three of which are domain-specific and the other two covering common concepts related to *shapes* and *tools*, respectively. The domain-specific ontologies are:

1. " *Virtual Humans* - formalizes the concepts and tools relevant to human body modeling and analysis, and the interaction of virtual human models with the virtual world.
2. " *Shape Acquisition and Processing* - conceptualizes knowledge related to the various processes encountered in the acquisition of shapes, for example by scanning.
3. " *Product Design* - covers knowledge that is useful within industrial product design, including the representation of shape semantics, the relevant processing methods and the product development work-flow.

© The Eurographics Association 2007.



(a) (b) (c) (d) (e)

Figure 1: *The bottom-up digital shape lifecycle applied to Virtual Humans*

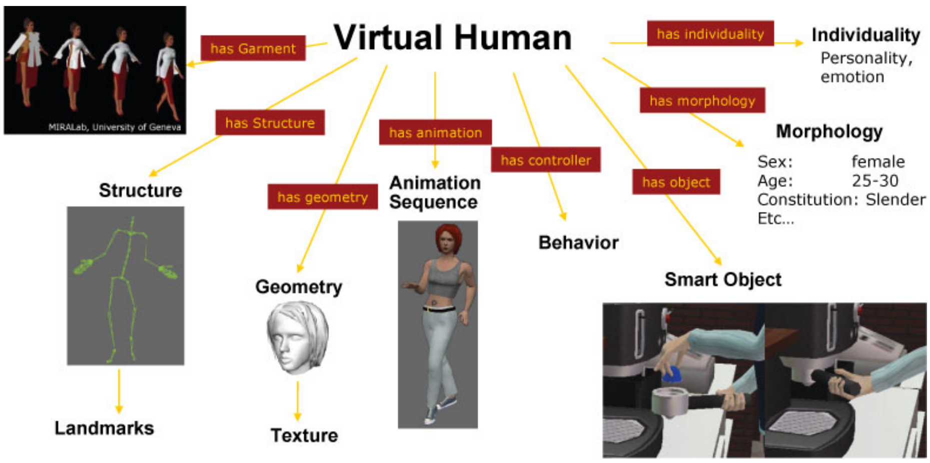


Figure 2: *General scheme of the Virtual Human Ontology*

3.2. The Digital Shape Workbench

The *Digital Shape Workbench* (DSW) is a common, web-accessible environment for sharing the resources and services provided by the consortium members. The main elements of the DSW are the *shape* and *tool repositories*, the common *digital library*, the *ontology and metadata repositories* and the *search engine*.

The role of the *shape repository (SR)* is to provide *quality* shapes of various kinds, that is, shapes with certified geometric properties and enriched with meta-data documenting the modeling history and purpose. A distinctive feature of this repository is its support for hierarchical storage and ability to provide models at several different levels of detail.

Certified software tools for processing digital shapes are shared via the *tool repository (TR)*, with special focus on documentation, tutorials, common formats and interoperability issues, see Figure 3 for an example of a shape model stored and processed by a tool in the repositories.

The *digital library* integrates the bibliographies of the consortium concerning shape modeling, and contains references and other reading material originating from or recommended by participating members or associated researchers.

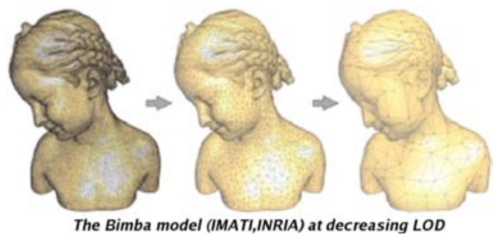


Figure 3: *A model stored in the SR and processed by a tool of the TR*

The *ontology and metadata repositories* handle the issues related to knowledge organization and ontology management, and are intended to provide integrated access to the shape and tool repositories and digital library through the associated *search engine*. This search engine uses deductive reasoning and inference to find digital resources match-

© The Eurographics Association 2007.

ing criteria specified by the user. There is currently ongoing work in extending the search engine with a natural language query interface.

An innovative *search engine* is currently under development, it is based on a semantic component for reasoning and a geometry-based component for content-based 3D shape matching and retrieval. In particular, the *semantic search engine* is used for simple search of resources uploaded into the ontology and metadata repository, but it also allows to acquire implicit knowledge pertaining to the available resources, by using semantic criteria and an inference engine. The *geometric search engine* provides content-based 3D shape retrieval mechanisms according to different similarity criteria and matching methods (e.g. global and partial matching, sub-part correspondence, part-in-whole). It adds to the DSW platform the possibility to act as a 3D retrieval benchmarking system.

Figure 4: *From geometric to semantic shapes via the analysis, the structuring and the interpretation of geometry*

4. Joint Research and Collaboration

The shift towards semantically capable digital representations of shapes requires a new perspective on the digital shape life cycle. It is necessary to determine where and how the semantics can be encapsulated in the modeling pipeline. The research program of AIM@SHAPE focuses on the three basic levels of shape-knowledge representation: *geometric* (low-level description), *structural* (configuration of relevant shape sub-parts) and *semantic* (meaning or function) (see Figure 4).

The research activities address the development of methods and tools for moving from one level to another, trying to preserve, extract and code shape knowledge during acquisition and reconstruction phases, analysis and structuring processes, interpreting and mapping stages.

In the *Acquisition and Reconstruction* phase, the focus is on preserving and enhancing shape data at all steps of the digitization process, which brings real objects into the digital world.

For instance, missing shape information can be reconstructed based on the semantic domain knowledge. Some covered research areas are *multi-level surface reconstruction* and *image segmentation*.

In the *Analysis and Structuring* phase, the geometry is analyzed in order to extract relevant features and structures which may help in the process of associating semantics to shapes. Examples of ongoing research topics in this category include *level-of-detail representations*, *shape characterization*, and *skeletal structures*.

In the *Interpreting and Mapping* phase we study and develop methods for annotating shapes with semantics and for interpreting semantics attached to shapes, within contexts like product modeling and applications involving virtual humans and the visualization of semantic information.

5. Further Information

The project is developed by the AIM@SHAPE Consortium Members (http://www.aimat shape.net/project/consortium/):

- C.N.R. - Istituto di Matematica Applicata e Tecnologie Informatiche (Italy);
- Università di Genova - Dipartimento di Informatica e Scienze dell' Informazione (Italy);
- Ecole Polytechnique Federale de Lausanne - Vrlab (Switzerland);
- Fraunhofer Institut (Germany);
- Institut National Polytechnique de Grenoble (France);
- Institut National de Recherche en Informatique et Automatique (France);
- Informatics and Telematics Institute (Greece);
- Max-Planck-Institut fur Informatik (Germany);
- SINTEF - Norwegian Foundation for Industrial and Techical Research (Norway);
- TECHNION - Israel Institute of Technology (Israel);
- MIRALab at the University of Geneva (Switzerland);
- Utrecht University (The Netherlands);
- The Weizmann Institute of Science (Israel).

Further information can be found at the AIM@SHAPE project website www.aimatshape.net.

© The Eurographics Association 2007.