Editorial: models and methods for representing and processing shape semantics

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1 INTRODUCTION

The technological advances in terms of hardware and software are leading to a progressive contraction of the universe of material objects, substituted more and more by immaterial representations, processes and services, where shape models play a crucial role. The wide availability of inexpensive PCs and the internet's impact on private and commercial communications is considerably changing the category of users; non-specialists and occasional customers demand easier access to 3D databases, and easier use of new technologies in their environment, wishing to use collaborative design, 3D multimedia, or online training and documentation. Shapes are then expected to take a central role in the Semantic Web in the next few years, with a high potential impact in several key areas. The European Community has clearly indicated, as main targets of the Sixth Framework Programme, the development of user-friendly interfaces, which should be: "coupled with more powerful and flexible knowledge technologies that are semantic-based and context-aware. They should prepare for the next generation Web and make access to, and creation of digital content more effective and more creative." Among the several research initiatives funded by the European Commission, is worth to mention the AIM@SHAPE Network of Excellence whose overall objective is building *semantic-based shape knowledge systems for the next generation Web*, where a description of a digital shape will be able to answer queries such as: "looks like, similar in a sense, belongs to this family of shapes, meaningful with respect to my request, makes sense to another one, etc."

The International Journal of Computer Applications in Technology has invited research and case study papers devoted to the definition of innovative 3D modelling approaches aimed at encapsulating knowledge together with the geometric representation of the object, at the different levels of abstraction needed for describing the object's form, structure and meaning. The response of the research community to the call for papers has been very good: high quality papers have been submitted mainly concerning the definition of appropriate tools and methods to extract, formalise and associate semantics to shape in specific context (such as engineering design, styling, virtual reality, manufacturing…). Thanks to the excellent work of many referees, to whom we are very grateful, the following 14 papers, here below briefly summarised, have been selected to be published in the Special Issue.

2 OVERVIEW OF THE PAPERS INCLUDED IN THE SPECIAL ISSUE

Due to the recent improvements to 3D object acquisition, visualisation and modelling technologies, the number of 3D models available on the web is growing more and more, and there is an increasing demand for tools supporting the automatic search for 3D objects in digital archives; traditional methods for 3D shape retrieval roughly filter shape information or perform a punctual comparison of models. Biasotti and Marini focus on the advantages of approaching the shape-matching problem through 3D graph-like descriptors, which decompose the shape into relevant subparts. In the presented approach, shapes are compared using a graph matching technique that includes a structured process, which identifies the most similar object portions. In particular, they investigate the properties of these descriptors and on the application of their matching method in the Computer Aided Design (CAD) context.

Focusing on the same topic as the previous paper, Ohbuchi et al. propose a pair of shape features for shape-similarity search of surface-based 3D shape models. Advantages of the proposed shape features are that they can be applied to non-solid or non-manifold models and are tolerant of topological and geometrical errors and degeneracy. They are also invariant to similarity transformation, that is, a combination of translation, uniform scaling, and rotation. Experiments showed that, with only a modest increase in computational cost, the proposed shape feature allows significant performance improvement compared to the original method on which it is based.

Retrieving technical drawings is a slow, complex and error-prone endeavour, requiring exhaustive visual examination, a solid memory, or both. The widespread use of CAD systems, while making it easier to create and edit drawings, exacerbates this problem: the paper of Fonseca et al. presents a new approach to classify, index and retrieve technical drawings by content. Different to conventional approaches, which use mostly textual metadata for the same purpose, the presented work uses spatial relationships, shape geometry and high dimensional indexing mechanisms to retrieve complex drawings from CAD databases. The described approach supports automatic indexation of technical drawing databases through drawing simplification, feature extraction and efficient algorithms to index large amounts of data. Some preliminary usability tests of the developed prototype are also illustrated.

The paper by Mukerjee and Muley focuses on a methodology for evaluating subjective aspects of 3D shape, such as aesthetics, by interfacing with an existing CAD tool. In this work, the authors attempt to capture that part of design meaning that includes emotional, aesthetic and other aspects of experience that are difficult to quantify. An important innovation is the use of a cognitively plausible set of primitives in defining the decomposition structure for conceptual design. By allowing the user to interact directly in the early phases of the design, such approaches are likely to present significant savings in the lifetime costs and also faster design.

In the early design phases, stylists need high-level tools to support properly their creativity. A curve-oriented design methodology seems to fulfil their attitude to sketch. In fact, the object character is impressed through certain curves, semantically important from the aesthetic point of view. Capturing such semantics is the intention of the modelling approach proposed by Catalano. The concept of styling features is here described and applied to a discrete surface representation, preferred to the standard splines in order to answer still exiting drawbacks of continuous representations along the entire development process. Features obtainable by means of generalised sweep operations are here defined and treated on subdivision surfaces. The choice of this type of feature is due to the expressive power in describing recurring shapes in industrial products.

The problem addressed by Faruggia et al. concerns the lack of computational tools that allow designers automatically extracting 3D shape models from *paper-based form* sketches during early design. To address this problem various Computer-Aided Sketching (CAS) tools have been developed. However, their digital sketching medium replaces the natural, portable and readily available paper. To address these issues, this paper reports the development of a framework which allows designers to obtain 3D virtual models and related life-cycle knowledge directly from early form paper-based sketches. The evaluation results of the implemented prototype tool, *X-SKetch*, provide a degree of evidence that this framework is a step towards making 3D geometric modelling software and computer technology available not only to designers but also to other users.

Renner and Stroud describe in their paper two techniques to improve the efficiency of the calculation process of the MAT Medial Axis Transform of planar polyhedral objects. The MAT surface, or simply Medial Surface (MS) offers the possibility of mathematically based volumetric reasoning about geometric models using global shape and proximity information. The MAT surface is an important tool which can be used for several applications, such as designing manufacturing applications, robot path planning and offsetting, but has the disadvantage that it is computationally intensive. The first technique is a thorough analysis of the cases, which can arise when calculating the vertex positions of the MAT of an object as combinations of points, lines and planes. The second technique is a divide-and-conquer method, which makes use of some properties of the MAT structure to subdivide the problem. The power of the algorithms is illustrated by some examples, which show the MAT of solid objects with complicated shape and structure.

Biancolini in his paper, presents a quality control procedure for corrugated board; corrugated board is widely employed in the packaging sector, because it is ecological, recyclable, and easily manufactured. The high production volumes involved makes attractive every action addressed to the optimisation because even a little saving in weight leads to benefits in money and environment. Mechanical performances of corrugated board panels are mainly influenced by starting material, corrugation shape, panel thickness and adhesive joint quality. The actual shape of corrugated board is acquired by a camera on line and digitised to obtain a mathematical representation suitable for the calculation of actual shape parameters and the manufacturing error introduced. The mathematical model of the actual shape is then used to generate a Finite Element Model (FCH) of material microstructure that allows the calculation of stiffness and strength parameters of the panel giving a direct estimation of material performances. Extracted parameters can be introduced in a control system that tunes the input parameters related to the shape error detected and maintains the performances within the desired range.

The preparation of FE models from CAD data is the topic of the paper by Leon and Fine; preparing a model for a FE analysis from a CAD model usually requires tedious tasks of geometric modelling to generate the component shape suited for that analysis. Detail removal and shape idealisation treatments are among the operations required to obtain the component shape for a given analysis. The presented research is aimed to demonstrate that an appropriate geometric model and a set of geometric operators may significantly improve the efficiency of the FE model preparation phase. It is also shown how these operators are associated to mechanical data to control the component shape changes while taking into account the mechanical hypotheses.

Pezzuti et al. in their paper illustrate an easy procedure to integrate three-dimensional cam profile synthesis and CAD. The authors developed an integrated tool which interacts with both CAD software and algebraic solvers in order to draw an accurate cam model and to compute performances as regard errors on position, acceleration and jerk. The basic idea is to combine an accurate kinematics analysis with shape modelling. Commercial software offers a simplified procedure to design cam profiles. The design of a three-dimensional cam is a very difficult task and the automatic modelling is even more complex because of the many variables to be taken into account. Moreover, in many industrial applications cam manufacturing is performed using enveloping techniques, neglecting accurate investigations of performance sensitivity due to approximation. For specific needs, as spatial cams, an appropriate and more accurate synthesis is required. On the other hand, the only geometrical design misses all the advantages of modelling, for example the correct calculation of mass properties, interferences, and the possibility to perform dynamical, impact and stress analysis in three dimensions. The presented methodology can help designers in the definition of digital mock-ups about mechanisms, in order to reduce time consumption.

Currently CAx systems (Computer-Aided Conceptual Design, Manufacturing, Engineering, etc.) allow to capture semantic information by introducing features on different levels of modelling; the knowledge about what a feature constitutes is embedded in the underlying application together with the operations that are applied to features in order to combine them or to modify their intrinsic geometric parameters. Brunetti and Grimm in their paper suggest to capture this knowledge in ontologies which can then be accessed by CAx systems as well as other applications. Their approach combines parametric modelling with techniques from the field of knowledge representation and ontological reasoning. Parametric models refer to feature ontologies that model feature semantics on several levels of granularity. On higher levels the interrelation between features and feature interoperability is captured, whereas on lower levels a feature is described in terms of geometric, topological, and parametric entities. Different engineering tasks can utilise feature ontologies as a basis for application specific shape reasoning across several modelling layers.

The representation of parametric and parametrically defined form features are under standardisation within the ISO-STEP community (ISO 10303). Today, ISO only provides a standard for the exchange of geometric and boundary models. Different to earlier papers that have addressed multiple feature views, Pratt and Srinivasan concentrate on the neutral representation of a core feature model compatible with the parametric representations generated by modern commercial CAD systems. This will allow the effective transfer of design feature models between CAD systems or between a CAD system and a downstream application system. The proposed representation adopts a three-level architecture for the representation of features at an application-independent level in the STEP standard. At the highest level is a generic representation of the procedural type. Below this is the canonical level, also procedural. Finally, the embedded level captures the feature in terms of elements of an explicit boundary representation model. Links between the three levels allow implicitly defined relationships between feature elements at the higher levels to be generated explicitly at the embedded level.

The scattered data approximation problem occurs in many applications, such as environmental sciences and medicine; the measurements are taken at irregularly spaced values of two or more variables, and often the reported values are affected by noise. In this perspective, the methods presented by Feraudi in her paper give the values of the approximating surface, evaluated at points on a rectangular grid covering the data set as a weighted mean of several local least squares polynomial approximations of degree at maximum three. The originality of the approach lies on the choice of the local supports used to define the polynomials; the basic idea is to take into account more information than just positional values, namely the intrinsic geometric properties of the surfaces, figured out from the given positional values. The choice of which geometric properties best describe the shape essence is then of fundamental importance.

Virtual Environments are used in a broad range of contexts, ranging from sophisticated Virtual Reality simulations to video games, and all sorts of interactive applications. Gutierezz et al. present an object representation based on the semantics and functionality of interactive digital items – virtual objects – within a Virtual Environment. Their research aims at defining a semantic model of virtual environments that helps on the adaptation, and re-purposing of both 3D models and their interaction mechanisms. They describe a semantic representation that captures the functions, characteristics and relationships between virtual objects. The model proposed is designed to turn the objects in a virtual environment into autonomous and reusable entities. Some test applications are described to demonstrate the benefits of the semantics-based representation of interactive virtual environments, including autonomous characters and collaborative environments.

Thanks to the fine work of the authors, we see in this issue a broad spectrum of methods and tools for representing and processing shape semantics applied to various problems, mainly in industry, but not limited to this field, that can represent a good starting point for future research. We have to see how these techniques can be combined and extended in order to provide solutions for the many requirements that arise in industrial applications.

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Silvia Ansaldi has a BSc in mathematics. She has experience in research and development activities in the fields of computer graphics, geometric and product modelling and data exchange among CAD systems. She has participated in several national and international research projects, working for CAD companies. She spent one year at the University of Rochester (NY) working on feature recognition and design. She has been in charge of several European Community research projects as a technical reviewer. She is currently the owner of a consulting studio in the support and development of design and graphic tools in the fields of mechanical and civil engineering.

Marina Monti has a BSc in mathematics. Until 1997 she worked in the Research and Development department of CAD companies in the fields of solid and free-form surfaces modelling and product modelling. During this time she has participated in, and has been responsible for, several national and international projects. Since the end of 1998 she has been part of the Computer Graphics group at the Istituto di Matematica Applicata e Tecnologie Informatiche in Genoa; she has been in charge of the technical reviews of project proposals for the European Community. She is involved in several international projects and her research interests include Computer Aided Design, product modelling and concurrent engineering.