Dagstuhl Seminar 98461
15.11.1998 - 20.11.1998

CAD - Tools and Algorithms for Product Design

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Preface

Continuously shrinking innovation cycles for technical products enforce highly sophisticated computer-based development tools. These tools need to go far beyond conventional CAD systems. Significant progress steps in research and development of CAD tools for the design of new products therefore are playing a key role in respect to the competitive power of complete industries.

This seminar at the International Meeting and Research Center for Computer Science at Schloss Dagstuhl Germany has focused on this important domain. Of particular interest are hereby methods for solid modelling, constraint and feature-based design of object families, product design, efficient integration of tools for calculation, simulation and analysis, design tools for very complex systems and assemblies, as well as rapid prototyping.
During the seminar, new solutions for these important problem areas have been discussed among leading experts. Besides the research presentations, this seminar has provided a forum for discussion and exchange of ideas and participant experiences. More than 40 scientists have participated together in 37 talks. In particular, they have focussed on new developments in different research areas:

New concepts for integrating the parametric thinking into aesthetic design and to devise an entire process chain integrating diverse requirements have been developed, and the connection between product structure and its geometric realization has been formalized. Parametric design has been generalized to product families in any domain by using product templates, and domain knowledge has been exploited to devise parametric models for electrical design.

Assembly-centric design is especially important in product desing because it is closer to a systems approach to design. An assembly-centric approach in the context of aeronautic design has been developed, and the importance of symmetry in assembly design has been stressed.
Product design requires integrating different domains, or views. Maintaining different views consistently and allowing views to make

domain-specific changes to the design is difficult. An approach to creating and maintaining differnt views consistently has been proposed in this context.

Optimization, user interaction and interfaces are a key accelerant in desing of very large systems. The problem of dealing with very large designs that stress our computational limitations has been discussed, and the role of virtual reality in design has been explored. Adding haptic interfaces to the designer's repertoire of interaction tools has also been discussed.

Despite extensive research, solid modelling and geometric constraint solving techniques are still inadequate for certain problems. Relaxation as a specific method to solve nonlinear equation systems arising in this context has been explored, and constraints for spatial design and manipulation have been studied. Other presentations have covered the construction of multi-resolution models - a useful technique when coping with massive detail -, meshing domains using a paving approach based on the medial axis, the use of conceptual steps in surface design, the analysis of surface singularities, the use of a wavelet approach to selectively simplify surface features and the systematic translation of knowledge association into parametric models.

The diversity and high quality of these contributions paint a picture of a field that is expanding and very active. With the continuing demands from manufacturing to increase efficiency, these contributions can provide some of the core strategies and tools to increase manufacturing efficiency and so contribute to increasing prosperity. Our thanks to the staff of Schloss Dagstuhl and to the Dagstuhl Foundation for its support, and to our collegues and contributors for sharing freely their profound knowledge and deep insights.

The Organizers

Pere Brunet *Chris Hoffmann* *Dieter Roller*

Generation of Solid Multiresolution Models

Pere Brunet

Universitat Politècnica de Catalunya

We present an automatic simplification algorithm that produces multiresolution models with piecewise algebraic implicit surfaces. The method is based on a spatial decomposition - initial voxelization of the model - and wavelet simplification. Like other spatial decomposition simplification schemes (MDCO, BSpline filtering) it simplifies geometry and topology. It can be used for navigation with LOD models in virtual environments or for approximate collision detection. The implicit simplified surface is defined as the zero-valued algebraic isosurface of a 4D functional tensor-product unform cubic BSpline. A wavelet multiresolution scheme that deals with uniform cubic BSplines on bounded domains has been constructed. One dimensional wavelet analysis and synthesis are defined on intervals with an even number (2n) of coefficient data, instead of 2^k. Storage requirements for coefficients are of the order of the number of initial voxels (surface area of the object). A suitable data structure and a way to estimate / reject data coefficients at each multiresolution step is also proposed.

Distributed Design Process Management Infrastructure

Martti Mantyla

Helsinki University of Tehnology

Development of product design processes and organisations have recently been characterised by two simultaneous developments: virtuality and layering.

Virtuality results from pressures such as increasing complexity of products, quality requirements and need to involve high technologies from multiple

domains. It has also been fuelled by opportunities of modern IT such as the Internet. All these have resulted increasingly often in product design processes which are carried out by a team of companies instead of a single firm.

Layering results from ever shortering lead-time requirements. If market demands design lead-time from product definition to mass production vamp-up of 6 months, there is precious little time for exploration and radical new design. The result is a separation of concept design from "actual" product design. In this arrangement, concept design develops proactively new product ideas that eventually may be included in products.

These developments mean that design as a whole is distributed both in space (virtuality) and in time (layering). This poses a whole range of research problems relating to product modelling, knowledge management and process management. New tools ofered by modern IT such as shared ontologies, agents and distributed object-based memory architectures may offer solutions matching these problems.

Virtual Engineering-The Role of Semantics in CAD - VR Integration

Joachim Rix

Franhofer-Institut fur Graphische Datenverarbeitung
Darmstatd
(Joint work with Gino Brunetti)

The globalization in product development calls for Co-ordination, Communication, and Co-operation. Information and Communication technology has to play a major role. Virtual Engineering will support the life circle needs of the engineering process from the design through manufacturing. To integrate

new interaction and visualization mechanism in the process, as available with Virtual Reality technology, two approaches are described:

- first, mapping of design and engineering data including the semantic information via a CAD server to the appropriate VR system. This step should also allow a back-propagation of interactive manipulations from the VR system back to the original data set in the CAx environment,

- second, integrating VR technology into the CAD environment. Intuitive interaction techniques guided by the semantic constraints will support the engineers work to use the existing design knowledge for correct modelling.

Efficient data structures defining and providing the appropriate parameters, constraints, and relations on the level of features, parts, or assembly are proposed. Examples on topological context based 3D interactions and interactive feature-based assembling were presented.

Virtual Prototyping: The Integration of Design and Virtual Reality

Antonino Gomes de Sa

BMW AG, Dept. Geometry Integration, CAD/CAM, Munich

The increasing competitiveness in the manufacturing industry force companies, for example, to reduce development costs and time and to increase product innovation, quality and flexibility to react quickly to new customers requirements. In this context a research project has been established in order to investigate the potential use of Virtual Reality techniques for the assembly and disassembly processes.

The presentation shows two different aspects that need to be considered and/or fulfilled, in order to achieve a significant added value and degree of integration: first, the requirements on the business process, in this case mainly assembly and disassembly processes and second, requirements on the system integration of design and virtual reality.

The today's implemented system architecture and business process strategy has been presented and with a virtual prototyping experiment, "change the bulb in the left tail light", various results of the different steps, for example, preparation of CAD data, reduction of complexity, conversion, etc. have been presented. Finally, some functionalities to intuitive interaction and manipulation with the virtual prototype have been shown.

FIORES - An European Project for a New Workflow in Aesthetic Design

Werner Dankwort

University of Kaiserslautern
(Joint work with Gerd Podehl)

Styling design is becoming a crucial mark for the success of automobiles on the global market. In most companies the process to get optimal styled cars are symilar: The shape of the car body is described by CAS/CAAD (Computer Aided Styling, Computer Aided Aesthetic Design), qualitatively evaluated regarding the desired characteristics , but the next optimization step is performed on the physical models. These loops are repeated several times.

- The BriteEuRam project FIORES is now trying to develop methods for optimization of the styling workflow by direct modification of aesthetic surfaces using the design intent in the sense of target driven design (Engineering in Reverse, EiR).

-This paper presents the mid-term results of the project: The styling processes are being analysed in different companies, the derived evaluation criteria are being formalized and directed to target driven design. The concepts of Engineering in Reverse are presented. Outlooks on further goals are given.

This work is the joint result of the project consortium (12 partners from 6 countries: automotive industry, styling enterprises, system suppliers, research institutions).

Geometric Modelling and Knowledge Representation

Ruediger Klein

DaimlerChrysler Research, Berlin

Design and engineering are knowledge intensive processes. Many different kinds of knowledge are used, and they interact in various ways during problem solving. A knowledge level design theory allows us to describe the main categories of design knowledge and their usage in an abstract way.

The same general principles can be applied to knowledge about geometry. The advantage of this domain is its well-defined semantics: due to the properties of physical space. The main geometrical knowledge categories and their relations can be identified. They behave quite differently under different geometrical modelling operations. From this ontology of geometry, the main interactions that an "intelligent agent" (knowledge based system or human) can perform with a geometrical modelling system can clearly be defined.

Variational Design in Electrical Engineering

Dirk Schafer

University of Stuttgart
(Joint work with Dieter Roller)

In the area of computer aided design for mechanical engineering (MCAD), one of the most important innovations of the last decade has been the introduction of parametric modeling. Now parametric modeling will be extended to the field of computer aided design for electrical engineering (ECAD). In this engineering area these-called technology of variational design will release a tremendous potential of cost and time reduction, simultaneously with a considerable improvement of quality. Hence, it can be considered as a significant base technology for next generation ECAD systems. After a brief

introduction, we state the main objectives of our project. Then we continue with a consideration of some substantial disadvantages which are inherent to contemporary ECAD systems.

After that, the technology of variational design in the context of electrical engineering is presented as one of the most promising approaches for disposing the above mentioned drawbacks. Furthermore, some application fields are discussed and the advantages of this new aspect of parametric modeling are summerized.

We also present a rough classification of variants and make some remarks about configuration-based project developement. Finally we close with some remarks about the establishment of a special working group "Variational Design in Electrical Engineering" that consists of experts from both industry and research, as well as experts from a CAD software company.

Conceptional Modelling with Geometric Constraints, Part I

Ulf Doring

Technical University of Ilmenau
(Joint work with Beat Bruderlin and Paul Michalik)

Modeling in the conceptual phase of the design process is not well supported by CAD-systems now. However, in this phase the main characteristics of products will already be defined. This paper discusses the main properties of design in the conceptual phase and the requirements to a system supporting conceptual modeling. Concepts of our approach to meet such requirements are described.

A key issue is order-independent declarative definition of models, in particular, we propose non-history based modeling with order-independent Boolean set operations by G-Rep solids, assembly and feature hierarchies and constraint solving for geometric, topological, numerical and conditional con-

straints. Examples of current conceptual modeling projects (2D and 3D) are given.

Conceptional Modelling with Geometric Constraints, Part II

Paul Michalik

Technical University of Ilmenau
(Joint work with Beat Bruderlin)

We investigate using constraint-based methods in a free-form curve and surface enviroment. In this work we concentrate on a problem at maintaining the curve-surface incidence relation while the curve is edited.

The method based on continuous function aproximation has been presented previously in similar context We formulate the relation between the DOFs and parameters (control points of the surface, curve resp.) as an explicit functional prescription. We show how the polynomial composition algorithm based on blossoms can speed up the computation and we propose a data structure for efficient storage of intermediate results.

We also discuss how to insert new DOFs, if the condition cannot be satisfied, and how a common solution space for several constraints of this type can be found.

CAD and the Product Master Model

Chris Hoffmann

University of Purdue

An architecture is developed for product master models. It federates CAD systems with downstream application processes for different feature views that are part of the design process. The architecture addresses especially the need to make persistent associations of design information with shape elements. Moreover, the design respects the need of commercial CAD systems (and of down-stream applications) to maintain proprietary information that must not be disclosed in the master model. In case studies, information flows are illustrated and how they are used to maintain coherence among the different views. Moreover, the task of automating a response to shape edit requests to the CAD model from downstream views, is seen to be a formal problem of reconciling different constraint schemata in many of the cases.

Reorganization of Product Depelopment Processes to Facilitate Mass-Customization

Jordan Cox

Brigham Young University

Methods for reorganizing the product development process were presented which proposed the development of "Product Templates". Product Templates are parametric templates of the entire product development process. Generic Solid Models are at the core of the templates and provide the ability to customize the designs of the products. Transformation of the product development process from a traditional mass-production approach to a mass-customization approach must be accomplished in order to fully develop effective templates. Multiple generic CAD models are created within each of the disciplines for the purpose of creating the necessary artifacts for product

development. A strategy for passing parameters between these models was presented which eliminated the need for passing geometry or relying on standards. The overall process of organizing and constructing a product template was presented and discussed.

Collaboration Across Multiple Product Ontologies

Mervi Ranta

Helsinki University of Technology

The product ontology research of the Product Modelling and Realization Group is based on the needs indicated by previous case studies on collaboration as well as system and enterprise integration. In particular the IMS/GNOSIS project realized a demonstration on the product life-cycle reaching from conceptual design through product family definition until manufacturing preparation and production simulation. The experiment showed that the challenge of facilitating collaborations lies in integrating independently developed inhomogeneous software systems of autonomous partners that cannot be assumed to be sharing any central product model or to be based on same standards.

Thus, the concept of facilitating a shared ontology is pragmatically unrealistic. We propose an architecture in which collaboration can be performed without ontological commitment, based on multiple related product ontologies. The architecture is based on brokering mechamism and communication through agents. Parters may use an ontology from the same domain (such as two subcontractors providing the same service) or from a related domain (such as marketing vs. design, or conceptual design vs. empodiment). The collaboration, which can be handled by the system encompasses the synthesis of the agent protocols based on the core ontology, creation of mappings between agent messages and local protocols, query definition, query mediation and conflict resolution.

Steps Toward a Relational 3D-CAD-System

Manfred Rosendahl

University Koblenz

Parametric 3D CAD systems are mainly history based. Problems arise, when a point or value depending on other items and not given as parameter, has to be changed to given position or value. Some concepts of a 2D relational system can be transfered. In 2D you can define a line tangent to 2 circles, in 3D you can have a truncated cone tangent to 2 spheres. But in 3D systems much more classes are needed, because the system has to hold the relations, the CSG-model and the Brep representation. It is essential to hold a transformation with the solids so when doing an animation for items built by boolean operations, these operations do not have to be recomputed, if the items change only their position and not their shape. Traversing the model-graph and propagating new values in the right order can be achieved by classes, derived from the already needed class for writing the data to a stream. Feature modelling can be done by segment definition and instances of the segments. These concepts are derived from procedures in programming languages.

A Geometric Relaxation Solver for Parametric Constraint-Based Models

Lluis Solano

Universitat Politècnica de Catalunya
(Joint work with Pere Brunet)

In this work, a new relaxation algorithm for solving geometric constraint-based 2D models is proposed. The algorithm starts from a constructive symbolic representation of objects (Constructive Parametric Solid Model) and proceeds by iterative relaxation of the geometric constraints. Models

can be defined with angle and distance constraints. A new algorithm based on an iterative global deformation of the system is presented and discussed, and its convergence is proved. The performance of hybrid algorithms involving global deformation and individual constraint relaxation is discussed on several practical cases.

Feature-Based Product Design

Wim Bronsvoort

Delft University of Technology

An overview is given of three recently finished projects in the context of multiple-view form feature modelling: feature validity maintenance, feature conversion and assembly feature modelling. Feature validity maintenance involves maintaining the meaning of features in a model, feature conversion deriving and maintaining several feature views on a product, and assembly feature modelling applying the concept of features to assembly. Some problems identified in this projects are indicated. These will be discussed further, and potential solutions will be elaborated, in the presentations given by Rafael Bidarra and Alex Noort.

Validity Maintenance in Semantic Feature Modeling

Rafael Bidarra

Delft University of Technology

One of the most powerful characteristics of feature-based modeling is the ability to associate functional and engineering information to shape information in a product model. Current feature modelling systems embody this

paradigm in their graphical user interfaces, providing the user with "engineering rich" dialogs aimed at the creation of feature instances. Most systems, however, fail to consistently maintain the meaning of the features throughout the modelling process. For example, a modelling operation on one feature may affect the semantics of other features without the user being notified by the system, let alone assisted in overcoming the situation.

Semantic feature modelling is a declarative modeling approach that not only provides a well-defined specification of feature semantics, but also effectively maintains this semantics during the modelling process, for all features in the model. This presentation describes the validity specification and maintenance mechanisms of the semantic feature modelling approach. The latter include: (i) detecting each invalidity situation, (ii) reporting it to the user, with appropriate explanation on its causes and effects, and (iii) providing the user with a convenient choice of reaction hints, aimed at recovering validity in the model. The high-level user assistance provided under this approach is illustrated whith an example modeling session.

Enhaced Multiple-View Feature Modelling

Alexander Noort

Delft University of Technology
(Joint work with Willem F. Bronsvoort)

With enhanced multiple-view feature modelling we want to support all product development phases using feature models. However, because product development consists of many phases, to start with, we will only support conceptual design, detail design, assembly design, manufacturing planing and assembly planing.

These phases will be supported by an extension of the prototype multiple-view form feature modelling system Spiff as it is developed at Delft University of Technology. This extension uses enhanced feature models instead of form-feature models in order to support a wider range of product development phases and uses a more powerful view management system that, in case no

interpretation can be found for a view, adjusts the existing models such that an interpretation can be found.

Enhanced feature models are built from features that have been defined as aspects of the product that have some functional meaning. This more general definition allows us to store functional information independently of product geometry and to store partial geometry. Together, these properties enable enhanced feature models to help enhanced multiple view feature modelling to support a wider range of product development phases.

The more powerful view management system is built around a view conversion system that uses feature linking, feature maping and feature recognition. Sometimes no interpretation can be found for a certain view because the model is unacceptable for the related product development phase. In this situation, the new view management system will try to adjust the model based on information about variant and invariant model aspects in order to turn it into a model that is acceptable.

Bounding the Distance of Splines from their Control Structure

David Lutterkort

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(Joint work with Jorg Peters and Dean Naivn)

A new bound on the distance between a function in B-spline form and its control polygon is introduced. This bound can be computed efficiently from a particular B-spline, which only depends on the (nonuniform) knot sequence of the B-spline basis, and from the second differences of the control polygon. In general, the resulting piecewise linear envelope follows the spline more closely than comparable constructive envelopes like the min-max or the convex hull envelope. The envelope can be used for an adaption subdivision algorithm with a-priori error bounds. Two simple applications are considered: (1) constructing a spline that stays above, but close to a given polygon,

(2) constructing a spline that stays in the channel between two given nonintersecting polygons. Both problems can be solved by a linear or a quadratic program.

What is the Role of an Arithmetic Division Operation in a Geometric Processing System?

Fujio Yamaguchi

Waseda University

For the last several years the present author has proposed Totally Four-Dimensional Homogeneous Processing or Homogeneous Processing in short [1] in order to achieve geometric processing without using a division operation, where geometric elements are defined in either classical projective space $\mathbf{P}^3$ or two-sided space $\mathbf{T}^3$, these vector space models are processed in an extended four-dimensional vector space, the principle of duality is made the most of, and projective invariance of geometry representation and computation is pursued.

The playground for the Homogeneous Processing is not a projective space itself but the associated vector space of a projective space. Therefore the Homogeneous Processing is essentially different from the scheme proposed by Stolfi [2] or described by Farin [3].

A Paradox

We have compared the characteristics of the Homogeneous Processing with those of the Euclidean Processing in terms of many evaluation items and found that the result turned out to be surprisingly favorable for the Homogeneous Processing and appeared to be contradictory to our common sense because the former is superior to the latter in almost all items. The result claims a paradox holds such that

> the Homogeneous Processing which provides the most general technique is, in reality, the most simple, stable, and accurate, and

furthermore provides the properties of generality, uniformity and duality which are really desirable in constructing a systematically organized computer-aided geometric design system.

The Role of an Arithmetic Division Operation

There is no need of carrying out any division operation during geometry processing. The homogeneous coordinate or coefficient data are sufficient for geometry processing. Division operations during each geometric processing do not create any benefit but harmful influences.

Then what is the real role of an arithmetic division operation in a computer-aided geometric design system ? It lies in the very end of the whole process, where the result is to be interfaced to the designer for the confirmation of his design intention. In this case homogeneous data must be converted to Euclidean data by division operations in order that he can easily understand the result. Ordinarily the division operations are carried out in performing perspective projections.

Conclusion

We would like to claim that we had better shift the playground for geometric processing from Euclidean to homogeneous one. We are organizing a research committee with Japanese industry engineers and examining the possibility of putting the Totally Four-dimensional Geometric Processing approach into practical use.

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[2] J. Stolfi: Oriented Projective Geometry, Academic Press, California, (1991).

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Similarity Issues - How to Compute Aesthetic Properties

Gerd Podehl

Universitaet Kaiserslautern

In engineering design one very often encounters the problem of not being able to yield the optimum result due to too many technological constraints. In aesthetic design the additional problem arises to also satisfy fuzzy constraints deriving from the stylists' intentions. Stylists and designers work on the same model trying to achieve superior surface quality with the originally intended shape character. A method for checking both is to derive from the surfaces patterns of evaluation lines (e.g. shadow lines, plane sections, reflection lines) and judge them from experience.

Within the FIORES project this process is going to be reversed by using an optimization loop in which targeted evaluation lines are used as an input and then calculates the underlying surface. In this loop a criterion is needed to evaluate how close the present solution is to the targeted one. This paper investigates the requirements that such an "aesthetic similarity criterion" must meet, and how it could be delivered from simple intrinsic curve properties. One result of these investigations is that similarity is a very context sensitive criterion which must be adopted to every specific application area.

A Simple Algorithm for 2D Mesh Generation by Domain Decomposition

Robert Joan-Arinyo

Universitat Politècnica de Catalunya
(Joint work with L. Perez-Vidal and J. Vilaplana)

An algorithm to yield a grid meshing of the polygon resulting from the domain composition of two previously meshed polygons is presented. The algorithm is based in the step-by-step advance of one front at each side of the region where the two poligons overlap. Examples of results are also presented to illustrate the method.

Triangulation Based versus Direct Segmentation of Unstructured Point Sets

Guido Brunett

Universitat Kaiserlautern

In reverse engineering one considers the automatic generation of a CAD model from a physical object. Typically, the r.e. process begins with the digitalization of the object. In the segmentation phase the point set is divided into segments appropriate for the surface fitting step. Very often the segmentation is based on a 3D triangulation of the data. In this talk the main tools for segmentation based on a triangulation as well as a direct strategy for segmentation are discussed.

Meshless Integration of Geometric Design and Engineering Analysis

Vadim Shapiro

University of Wisconsin - Madison
(Joint work with Igor Tsukanov)

Geometric design ang engineering analysis have emerged as two separate activities that are only weakly connected, because they operate on distinct computer presentations, and require difficult representation conversions, such as finite element meshing and grid generation.

We propose to develop a new technology aimed at seamless integration of geometric design an engineering analysis tools using a single hybrid computer representation. The new representation combines an implicit function of the geometric model with a piecewise continuous model of the analysis problem. Such representations can be constructed automatically and support MESHFREE analysis of spatially distributed problems, where the spatial discretization no longer needs to conform to the geometric domain or boundary conditions.

A Modeller for Preliminary Design

Jean-Marc Brun

Universite Claude Bernard Lyon 1

An approach to enable CAD's use in the early stages of design is proposed. This approach comes from an analysis that shows that the design process is based on two coupled descriptions: the Product Requirement lists (PRl) tree and the Physical Product (PP) tree. The design process itself expands progressively the PRl tree while translating it in components of the PP tree, these two trees being interleaved by functional relations. The product consistency migrates progressively from the PRL tree to the PP tree and the

geometric model bears the essential part of the PP consistency at the end of the process.

Since CAD-CAM geometric models are too precise, complex and difficult to handle for preliminary design which is primarily functional and geometrically fuzzy, a preliminary design model is proposed. This model links functional descriptions to geometric models through functional form features that are parametrized and more or less idealized.

Idealization can remove details like fillets, grooves or holes, when not relevant for the process, while maintaining their existence as non instanciated features which are parametrized modifiers of the shape. Some features can be replaced by 2D (shells or plates) or 1D (fibers or bars) idealizations, bearing nevertheless thickness parameters (eventually variable) and edge modifiers (rounding or chamfering).

After some remarks on the use of features in a multiview environment, an example of preliminary design is presented that shows a "typical" designer working in the proposed environment.

Planar-Domain Simplification for 'Void Modeling'

Nick Sapidis

National Technical University of Athens
(Joint work with Gabriel Theodosiou)

Complex mechanical systems involve functionality constraints implying empty-volumes that must exist at specific locations. These may be modeled as "virtual solids" using standard solid modeling techniques like "extrusion". This requires an efficient simplification algorithm for planar domains. Such an algorithm is proposed in this talk, wich is based on examining all possible sequences of edges that might be simplified. A property involving the

domain and its bounding box is stablished that limits the parts of the domain's boundary that the algorithm must consider. Examples are presented that demonstrate the validity of this algorithm and the effectiveness of the implementation, in the sistem AutoCAD, produced by the authors.

Finally, a detailed analysis stablishes the advantages of the new algorithm over published techniques from the fields of "automatic nesting", "automatic finite-element meshing" and "virtual reality".

Discrete Surface Extraction with Minimal Wrinkles

Alvar Vinacua

Universitat Politècnica de Catalunya
(Joint work with Pere Brunet, E. Monclus, I. Navarro)

We present an algorithm to extract isosurfaces from a maximal subdivision classical octree or a voxel model of a part, using a tetrahedrization of the cubes and discrete weights at the vertices. The weights are tuned for the tetrahedrization used in such a way that the different tetrahedra admit the exact same set of support planes for the faces contained in them. As a result, a filtering process is possible, such that neighbouring faces tend to coalesce into bigger faces, yielding a simple model, and also a model closer to the original when starting from, for example, mechanical parts

Rapid Developement of Building Models

Alberto Paoluzzi

Universitá di Roma Tre

Conceptual modeling and preliminary design are the stages of the design process where current CAD systems offer only minimal support, despite their fundamental impact on the whole product development process. This is particularly true in Computer Aided Architectural Design systems. It is our opinion that the early formalization, visualization and check of initial design concepts may give the architect a valuable design tool.

At this purpose we suggest the functional design language PLaSM and discuss the collaborative design of a tower building as a paradigmatic example. In particular, it is supposed that three different teams collaborate to the design by developing the schematic layout and elevation, the rigid kernel and the courtain walls. The close correspondence between symbolic representations and shapes is discussed.

The language, characterized as a functional approach to computing with geometry, has been recently extended with colors, textures, lights, user-definable viewpoints and animation. It can currently export in various VR data formats, including VRML1, VRML2 and Open Inventor. The generated models can so be distributed on the web and easily shared with both the partners and the customer, in order to receive feedback and/or approval.

Some necessary extensions of the PLaSM programming environment are finally outlined, including a graphical/visual user interface, a type subsystem to support the "prototyping" of parametric models or parts, and a logical subsystem to support geometric reasoning. Some preliminary experiments to re-implementing the language with either SML or Ocaml are also discussed.

Feature-Based Assembly for Aeronautics Design

Umberto Cugini

Universitá di Parma

The design of mechanical assemblies carried out using today's CAD systems is mainly developed by modeling single parts, and then assembling them in a subsequent design phase. This bottom-up approach is not congruent and not satisfying the way designers are used to design assemblies. The introduction of the feature-based approach in assembly design would allow the designers to start drawing the assembly using a top down approach leaving the design of details and sub-systems to a following phase. This paper presents some results of the research activity done within the framework of the Brite/Euram II Project FEAST (FEature based ASsembly Techniques) funded by the European Union (Feast Report, 1994), aiming at extending and validating the use of features, to help in the solution of assembly problems in aeronautical applications. The work has focused on the analysis of design of assemblies, and on the study of the assembly-feature technology, and how it can be used and embedded into a commercial CAD system. First, a detailed analysis of assembly design has led to a classification of assembly product structure. Then, the concepts developed have required to be formalised and provided as system knowledge. Therefore, it is necessary that the experts validate and test the system. This process is typical of software development, where reiteration from specification to implementation is often required. This process is obviously time consuming and costly.

The paper describes the knowledge formalisation process we have followed, and then illustrates an alternative method to knowledge implementation and validation. This consists of the design and implementation of a demonstrator that allows users to validate the formalised knowledge of a feature-based assembly environment, before implementing the actual system. The demonstrator is meant to be an interactive system that simulates a real CAD system, and provides the possibility to show to the end users how the system might be, and how to interact with it.

Finally, a prototype of the system implemented using a commercial CAD

development environment has been developed based on the validation done by designers through the demonstrator.

Constructive Methodology for Surface Modelling

Abdelaziz Bouras

Universite Claude Bernard de Lyon

The aim of the presented methodology is to simplify the design of complex surfaces. It helps the user to design his shape step by step, using a constructive logic. This logic is based on a shape algebra and a description language. The shape algebra uses mainly primitives and operators. The primitives are either classic ones (curve arcs, surface patches...) or with dimensional parameters ("standard curves"...). The operators are classified according to different criteria: topological dimension of their resulting figures, number and classes of their arguments, or performed task. Two main operators are detailed: surface joining and suface intersection. A fuzzy geometry concept is presented to face the problem of tangency between surfaces (complex calculation) and small loop detection. The fuzziness value controls the needed precission for calculations. Some examples related to complex surface definition and reconstruction are presented.

Navigation in Highly Polygon-Populated Ship Environments Using the Visibility Octree

Isabel Navazo

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(Joint work with Pere Brunet, Carlos Saona)

This work is focused on the interactive navigation through very complex polygonal models. There is a wide range of applications nowdays whose requirements surpass even the most expensive high-end graphics workstations. To name a few, ship design, architectural design and virtual reality applications have hundreds of thousands or even millions of polygons. Current graphics hardware is not able to cope with this kind of scenes at interactive frame rates.

The Visibility Octree (VO) is a new data structure to accelerate 3D navigations through very complex scenes. A conservative visibility algorithm that computes and store hierarchically this new structure at a preprocessing stage is presented. The Visibility Octree is used during navigation and its main contribution is its ability to provide an effective control over the coarseness of the visibility approximation. The algorithm builds the VO recursively in a top-down way. Each node's visibility is computed in terms of the visibilities of its eight vertices. If the number of visible objects is sufficiently small, the node is a terminal node of the VO and the subdivision stops. If not, the algorithm decides between subdividing the node and increasing dynamically the number of considered occluders. The algorithm uses a bounding box hierarchy that is specially well suited for ship environments with a large number of axis-aligned pipes and dividing walls.

Tests with some randomly generated ship indoor scenes show that the VO will perfom well on densely occluded scenes.

Tools for Assembly-Oriented CAD

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(Joint work with S.J. Tate, Cranfield University and K.G. Swift, Hull University)

The design process supported by present CAD tools tends to be component oriented rather than dealing with a product as a whole. Furthermore, design evaluation tools often need complete product descriptions to give meaningful results. This paper gives a brief account of the architecture and capabilities of an assembly-oriented design environment that is currently being developed. Particular emphasis is given to the geometric reasoning functions needed within it.

One of the tools available in the assembly-oriented environment is Design for Assembly Analysis (DFA). Many of the evaluation criteria used by DFA are based on calculations from geometric properties. The need to discover whether a component is symmetric arises in several DFA evaluation criteria. An algorithm for "symmetry detection" is presented.

An Algorithm for Fast Picking and Snapping in 3D

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This paper presents an algorithm that allows fast 3D picking and real-time snapping with a 3D cursor on considerably complex CAD models. The run-time behaviour of the algorithm is nearly independent of the model complexity. In contrast to conventional ray picking, the minimum distance of a 3D cursor to the model surface is calculated. This time-consuming nearest point

calculation is crucial in the algorithm, so the number of nearest point calculations have to be minimized. For this end , we apply a multi-level bounding box check and use coherence between succeeding user interactions to allow the cursor to slide along the model surface in real-time. The algorithm works with the precise CAD model not only on a triangulated representation as collision detection usually does.

Organ Reconstruction, Dimensioning Prosthesis

Dominique Michelucci

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(Joint work with F. Banegas, M. Jaeger, M. Roelens)

In medical applications of geometric modelling, reconstructing a multiresolution description of shapes from 3D data images (obtained from scanner, tomography, IRM) is one of the key issues today. We propose such a method, originating from the field of statistical analysis of data.

After the segmentation step, the shape to be reconstructed (bone, organ) is described by a set of voxels, inside or on the boundary. The best ellipsoid fitting the points is computed: its center is the gravity center of all voxels, its main axis are eigenvectors of the dispersion matrix of points. It gives an initial classification with one class, or one ellipsoid. Then the decomposition into main components and the dynamic clustering technique permit to refine interatively this classification, and to find the best partition into ellipsoids to fit the point set. A hierarchical classification is obtained in the end. For a prescribed level of details, induced ellipsoids are blend-unioned with Blinn's method. An imminent application is the automatic dimensioning of prosthesis.

The classification is very stable. We hope to be able to use this property for matching medical shapes. It would allow to follow and monitor the evolution

of pathologies, or a more automatic detection of some pathologies for the moment, such a detection is a highly interactive process with a physician.

Differential Properties of Parametric Surfaces at Singular Points

Yasushi Yamaguchi

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Differential properties are essential for many kinds of surface applications. Surface rendering, surface-surface intersection, off-set surface generation, and so on require differential properties. In differential geometry, there are certain assumptions which guarantee the existence of differential properties. Surfaces that guarantee such assumptions are said to be regular. However, in the practical application, surfaces may have singularities where we cannot calculate differential properties in a usual manner. This talk is aimed at calculating differential properties at the singular points where they can be uniquely determined. The proposed techniques are able to define normal vectors as well as curvatures in a uniform manner.

The Role of Haptic Devices for an Efficient Integration of Design, Simulation and Analysis

Monica Borgedoni

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(Joint work with Franco De Angelis)

In the simulation evolution trends one of the main issues concerns providing operational modality at higher and higher level and more and more user-oriented. That can be achieved by introducing new interaction paradigms and new technology in the simulation phase. In the evolution of geometric representation we consider Digital Mock Up intended as a realistic computer simulation of a product.

Our research work intends to concentrate on this concept of "realism" required in simulation environments. Following this trend we are considering and testing haptic interaction with DMUs, allowing users to feel several physical properties of the model.

Besides, considering the evolution from geometric-based to physically-based modelling, we have integrated haptic interaction modality with the simulation of non-rigid objects, modeled according to a physically-based approach. To this purpose, we have developed a high-speed approximated simulator of non-rigid objects, allowing haptic rendering of computer physically-based models in real time.

Selective Encoding With Haar Wavelets

Alexa Nawotki

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The results of an encoding-method is usually useless for anything but decoding. Quite often only a part of the information is needed and right now

you cannot transmit only that data, you must pass on all the information or nothing. Thus I show a way to construct intermediate versions of the data with gradually reduced informations. Critical parts of the data are filtered out.

The central idea for solving this problem is to utilize wavelets: A wavelet-decomposition consists of a hierarchy of details, i.e. the original function is split into its smooth and rougher parts with amplitudes of different sizes. Intuitively, little modifications of the original function results from a change of the coefficients belonging to a base with small elongation, and vice versa a variation of the "smooth" coefficients causes large differences.

The request by Hella KG Hueck & Co., which sponsored this research, was to construct an intermediate version of a reflector in a headlight with modified reflection-pattern and unchanged geometry. I achieved that with Haar-wavelets and I show in addition an a priori error estimation.

Mechanism Analysis Using Multidimensional Set-Theoretic Modelling

Kevin Wise

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(Joint work with David Eisenthal and Adrian Bowyer)

The rotational structure of set-theoretic modelling is dimension independent. We describe how a multidimensional geomertic modelling approach can be used to combine these separate strands of research into an integrated mechanism analysis system.

First, feature recognition is used to deduce constraints imposed on a mechanism by its lower kinematic pairs. This information is fed to a constraint modeller in which constraints are formulated as multidimensional sets in con-

figuration space where the solution set is their intersection. Finally, obstacles in the configuration space caused by interacting shapes are computed by analysing a multidimensional model in which additional dimensions are used to represent degrees of freedom. A hybrid method is employed which uses precise analytical techniques where simple shapes interact, and approximate heuristics elsewhere. We also discuss the use of extra dimensions to represent design parameters in order to provide a framework for design optimisation.