Activity Report 2013

Team CAD

Computer Aided Design

RESEARCH CENTER
Paris - Rocquencourt

THEME
Computational models and simulation

Table of contents

Team CAD

Keywords: Geometry Modeling, Curves And Surfaces, Visualization, Rendering, Image Processing

Creation of the Team: 2009 January 01, end of the Team: 2013 December 31.

1. Members

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Jun-Hai Yong [Team leader, Tsinghua University, Professor, HdR]
Bin Wang [Associate Professor, Tsinghua University, HdR]
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External Collaborators

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PhD Students

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Yong Zhang [Inria, Graduated from Tsinghua University]
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Administrative Assistant

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2. Overall Objectives

2.1. Geometry

In Computer Aided Systems, the mathematical representation of curves and surfaces are based on parametric surfaces. This representation is very practical for the designer. The designer can create curves and surfaces very easily with control points and basis functions that influence the domain of control points. However, there are a lot of theoretical and practical computational problems with these surfaces. From 2004, our overall objective in CAD is based on new *Differential Geometry* contributions. We have found find original ways to address these problems: continuity, geometric operators (see Section 2). In the next two years, we want to improve our contributions in geometry for CAD, but also to extend our contributions and address related *Engineering* and *Manufacturing* problems.

2.2. Computer Graphics

In Computer Graphics, we addressed various topics: Lighting, Computational Photography, Computer Animation. In the nest years, we plan to explore a new research avenue in a new very attractive and open problem in Urban and Architectural models design.

3. Research Program

3.1. Geometry

3.1.1. Geometry Continuity and epsilon-geometry continuity

In differential geometry, Riemann (1826 1866), continuities play a very important kernel role. G-Continuity could be defined as the smoothness properties of a curve or a surface that are more than its order of differentiability. To day, scientists try to find a kind of continuities, which are the intuitive intrinsic properties of curves and surfaces, and the orders of the continuities are independent of the parameterization. In order to make through the bottleneck, we have developed the theories of epsilon-geometry continuities to accommodate the representation and the rounding errors of float-point arithmetic, and designed new geometric modelling operators under the constraints of epsilon-geometry continuities. Since representation and rounding errors of real numbers by floating-point numbers are ubiquitous, we have developed the epsilon-geometry continuity theories and algorithms with error tolerances to match both the features of the floating-point arithmetic and the requirements of the engineering design. Thus, we proposed the theories and algorithms to manipulate the transition between sharp and rounded features. We have provided theories and algorithms for the $\epsilon - G^2$ B-spline surfaces interpolating the specified four groups of boundary derivative curves in the B-spline form. We bound all kinds of the discontinuities by the invariant tolerances, and classify the compatibility problems. Then, we proposed the algorithms for continuity-preserving re-parameterization, knot-insertion and local control-point tuning to solve the compatibility problems, and achieve the $\epsilon - G^2$ continuities.

3.1.2. Geometry beautification

Although geometric uncertainties are often related to robustness and tolerance, there are a number of extra issues well worth deeper investigations. Geometric arrangements are full of special cases. The most notable ones are: cases of touch, overlapping, containment, etc.; cases of parallelism, perpendicularity, coincidence, etc.; axes of symmetrical data, data clustering, dense or sparse data, etc.; cases of degeneracy, discontinuity, inconsistencies, etc.; problems with cracks, excess material, lack of detail, etc. In just about any code that deals with geometry, the number of special cases is significantly larger than the general ones. Data explosion is the result of careless selection of the methods, e.g. parameter space-based sampling, and improper implementation, e.g. recursive algorithms. Some of the relevant issues are: sampling: over sampling, sampling in incorrect places, etc., procedural definitions, e.g. lofting a large set of curves or merging surfaces may result in an explosion of control points. Our contributions in the last years proposed elegant solutions to deal with these problems.

3.1.3. Shape generation

As an alternative solution to NURBS, we proposed a canonical form of the curved-knot B-spline surface called the regular curved-knot B-spline. The curved knot vector of one parametric coordinate is defined by a group of blending functions that depend on the other coordinate. So the knot vectors of two opposite boundaries can be different. That property makes it possible to represent a smooth transition between two B-spline boundaries with different knots and continuities, since knots determine the continuity. The regular form guarantees the simplicity in storage, evaluation and construction algorithms. It therefore provides the curved-knot B-spline with practicability in geometric modeling systems. The applications of surface bridging and transition illustrate its suitability for blending sharp and rounded features. Compared with B-splines and T-splines, it not only increases the surface quality, but also reduces the complexity of the surface construction.

We mention here papers published in the best international reviews in CAD i.e. *Computer-Aided Design* (*Elsevier*) and *Computer Aided Geometry Design* (*Elsevier*) in the last four years.

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3.2. Computer Graphics

3.2.1. Real-time ink simulation

We have presented effective methods to simulate the ink diffusion process in real time that yields realistic visual effects. Our algorithm updates the dynamic ink volume using a hybrid grid-particle method: the fluid velocity field is calculated with a low-resolution grid structure, whereas the highly detailed ink effects are controlled and visualized with the particles. To facilitate user interaction and extend this method, we proposed a particle-guided method that allows artists to design the overall states using the coarse-resolution particles and to preview the motion quickly. To treat coupling with solids and other fluids, we update the grid-particle representation with no-penetration boundary conditions and implicit interaction conditions. To treat moving "ink-emitting" objects, we introduce an extra drag-force model to enhance the particle motion effects. Our work is attractive for animation production and art design and is popular in China.

3.2.2. Content-Based Color Transfer

We have presented a novel content-based method for transferring the color patterns between images. Unlike previous methods that rely on image color statistics, our method puts an emphasis on high-level scene content analysis. We first automatically extract the foreground subject areas and background scene layout from the scene. The semantic correspondences of the regions between source and target images are established. In the second step, the source image is re-colored in a novel optimization framework, which incorporates the extracted content information and the spatial distributions of the target color styles. A new progressive transfer scheme is proposed to integrate the advantages of both global and local transfer algorithms, as well as avoid the over-segmentation artifact in the result. Experiments showed that with a better understanding of the scene contents, our method well preserves the spatial layout, the color distribution and the visual coherence in the transfer process. This work is useful for Computational photography and film industry.

We mention here papers published from the last four years in the best international reviews in Computer Graphics i.e. ACM Transactions on Graphics, ACM Siggraph / Siggraph Asia, IEEE Transactions on Visualization and Computer Graphic, Computer Graphics Forum and The Visual Computer (Springer Verlag).

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4. Application Domains

4.1. Domain

Computer Aided Design and Computer Graphics are two Application Domains.

5. New Results

5.1. Geometry

5.1.1. From CAD to Engineering: Computing FEM on curved surfaces

Participants: Jean-Claude Paul, Kan-Le Shi, Yu-Shen Liu, Jin-San Cheng, Cheng-Lei Yang, Bruno Durand, Jun-Hai Yong.

In cooperation with Bruno Lévy (Inria)

The cooperation with EADS, based on our new B-Spline surface formulation, was very promising, for complex shape modelling. Our surfaces are very efficient in term of precision. Moreover, they avoid the control point explosion of NURBS surfaces. We propose our work in two directions: 1) to Improve the Modelling process for the user (it is a strategic point of the success of our new mathematical surface); 2) to take profit of the control points way of our surface to compute numerical simulation on this surface directly. In industry, Geometry design and Engineering employ a sequence of tools that are generally not well matched to each other. For example, the output of a computer aided geometric design system is typically not suitable as direct input for a finite-element modeler. This is usually addressed through intermediate tools such as mesh generators. Unfortunately, these are notoriously lacking in robustness. Even once a geometric model has been successfully meshed, the output of a finite-element simulation cannot be directly applied to the original geometric model, since there is no straightforward mapping back to the original design degrees of freedom. Additionally there is a need for a trade-off between the speed of analysis and the fidelity of the results. In the early stages of design, quick results are necessary, but approximate results are acceptable. In the later stages, highly precise results are required, and longer computation times are tolerated. Worse, different underlying models are required for each level of refinement. These difficulties make the design process cumbersome and inhibit rapid iteration over design alternatives. We plan to use FEA on Knot vectors surfaces directly (i.e. use the same function basis for the Geometric Modeling and the Numerical Simulation Process. We will apply this approach to fluids analysis: turbulence modeling (fluid-structure interaction). We think that our surface functions exhibiting higher-order continuity are an ideal candidate for approximating such flows. From the practical point of view, the main objectives of the study are to evaluate, in the scope of this application, the efficiency of such approach in term of simulation accuracy, simulation time and computational convergence. We also aim to evaluation how such approach deals with simulation accuracy/convergence according to CAD definition (quality/size of patches used to define the 3D shape).

5.1.2. *From CAD to Manufacturing: Robustness tolerance and error control*

Participants: Jun-Hai Yong, Yu-Shen Liu, Clara Issandou, Hai-Chuan Song, Lu Yang, Kang-Lai Qian, Jean-Claude Paul.

In cooperation with Dr. Nabil Anwer – ENS Cachan and the Tsinghua PLM Center (supported by Dassault System). Dr. Yi-Jun Yang (Shandong University), Dr. Xiao-Diao Chen (Zhejiang University)

Based on our theoretical contribution in Differential Geometry, especially about our ϵ-Geometry Continuity and our new geometric operators we proposed several elegant solutions to the most important challenges in Computer Aided Design (see Lees A Piegl. "Ten challenges in Computer-Aided-Design". Jal of CAD 2005. 37 (4): 461-470): robustness, tolerances, error control. During CAD processes one uses a myriad of tolerances, many of which are directly related to the actual manufacturing process. Some interesting questions here include: What are the most relevant machining tolerances? How to set the army of computational tolerances, e.g. those of systems of equations, to guarantee machining within the required accuracy? How tolerances in different spaces, e.g. in model space and in parameter space, are related. Numerical instabilities also account for the majority of computational errors in commercial CAD systems. The problems related to robustness haunt every programmer who has ever worked on commercial systems. Fixing numerical bugs can be very frustrating, and often times results in patching up the code simply because no solution exists to remedy the problem. We first plan for assisting the designer when specifying the functional tolerances of a single part included in a mechanism, without any required complex function analysis. The mechanism assembly is first described through a positioning table formalism. In order to create datum reference frames and to respect assembly requirements, an ISO based 3D tolerancing scheme will be proposed, thanks to a set of rules based on geometric patterns and TTRS (Technologically and Topologically Related Surfaces). Since it remains impossible to determine tolerance chains automatically, the designer must impose links between the frames. We want to develop proposes ISO based tolerance specifications to help ensure compliance with the designer's intentions, saving on time and eliminating errors.

5.2. Computer Graphics (2010-2013)

5.2.1. *Inverse Procedural Modeling of Facade Layouts*

Participants: Weiming Dong, Bin Wang, Dong-Ming Yan, Hua-Liang Xie, Jean-Claude Paul.

We want to address the following open research problem: How can we generate a deterministic shape grammar that explains a given facade layout? An approximate dynamic programming framework will tackle this problem. The proposed solution contributes to the compression of urban models, architectural analysis, and the generation of shape grammars for large-scale urban modeling. As a major contribution of this work we want to formulate the inverse procedural modeling problem for facade layouts as a smallest grammar problem. We also want to propose an automatic algorithm to derive a shape grammar for a given facade layout. In this work, we will assume segmented and labeled facade layouts as input and do not derive the shape grammars directly from photographs. The joint optimization of segmentation and grammar extraction remains an aspirational goal for this work.

5.2.2. *Architecture Design*

Participants: Jean-Claude Paul, Bin Wang, Weiming Dong, Lin Li, Yan Kong, Yong Zhang, Fan Tang, Fuzhang Wu, Cui-Gong Wang.

In cooperation with UC Berkeley - Department of Architecture

We want to propose a method for automated generation of architectural models for computer graphics applications. Our focus is not only on the building layout: the internal organization of spaces within the building, but also the Architectural composition of volumes, roofs and facades. We focus on the generation of various types of buildings: residences, schools, museums, hospitals, civic enters, office buildings. Our work builds on grammar-based procedural modeling, inverse procedural modeling and composition rules, especially symmetry and scaling, and interactivity. Moreover, we consider the architecture design process as an iterative trial-and-error process that requires significant expertise and learning by doing.

6. Bilateral Contracts and Grants with Industry

6.1. Bilateral Contracts with Industry

6.1.1. Geometry

We contributed to some industrial applications, mainly:

- Aircraft industry: Design of winglets (with EADS)

  In this project, our aim was to improve the geometric preprocessing of the CAD models generation that were used for the manufacturing of the multi parted wing-fuselage configuration and the generation of the numerical grids for the corresponding numerical simulations. We try developing algorithms for automatic generation of winglets with different bending radii, angles and top views. Some of the methods for approximation, fairing, modeling and grid generation used for this task are in principle well known in literature. However, standard commercial CAD systems cannot be used for the modeling of the surfaces because they do not provide the interfaces to fulfill the special constraints, which stem from the design wishes and the manufacturing and the needs of the applied flow solver for the aerodynamics equations.

- NC Simulation (with Spring Technologies)

  The aim of this work was to rebuild a CAD file (Brep, STEP format) from the result of a machining simulation (set of triangles). Any CAM software would use this reverse engineered model for any further application (inspection / FEM / definition of further tool paths). Another expected application was to rebuild CAD files from old G -code programs for which the initial CAD files do not exist anymore (or had never been modeled in 3D). Spring NCSimul provides a set of triangles as a solid. This set is topologically closed and represents a single solid. All data could be used to help gather triangles by geometric entities and then to help compute the exact surfaces. Different types of machining operations have been considered: Machining of simple shapes: The movement of the tool generates the same kind of surfaces as the tool ones: planes, cylinders, torus, etc. and Machining of complex shapes: the tool moves on a surface (canonic surface as well as NURBS surface) along a point-to-point path. Here, the reverse engineering is far from straightforward and the surface recognition would be computed at a tolerance.

- Dam Construction (with CHIDI / Dassault System)

  Once the digital terrain modeling and the geological shapes are represented, dam design issue is one of the most important difficult applications for geological modeling. This issue considers a multiple geometric representation of geological and design features. The dam design is based on NURBS surfaces representation and parametric design is an important key point when modifying shape or geometrical parameters and properties. In the other hand, geological shapes are mesh-based (surface meshes for geometrical characteristics, and volume meshes for material and engineering properties). In the plant interaction, we have impact the dam basement on the geological modeling. That is to say, remove a solid to a mesh. Then map geological properties to the solid. At this time, there was no feasible well-designed NURBS-Mesh Boolean operation algorithm in both research and industrial field and the aim of our work was to develop a stable NURBS-Mesh Boolean operation algorithm. This long-term work was developed for the CHIDI Company (Chengdu) with the participation of Dassault System. Moreover, in order to provide simulations after the Earthquake in Sichuan, we first focused our work on the Boolean operation algorithms.

6.1.2. Computer Graphics

6.1.2.1. Image resizing (with Shanghai Film Studio)

We have developed an image resizing method that succeed in generating impressive results by using image similarity measure to guide the resizing process. An optimal operation path is found in the resizing space.

However, the slow resizing speed caused by inefficient computation strategy of the bidirectional patch matching becomes a drawback for practical use. Then, we proposed a novel method to address this problem. By combining seam carving with scaling and cropping, our method can realize content-aware image resizing very fast. We define cost functions combing image energy and dominant color descriptor for all the operators to evaluate the damage to both local image content and global visual effect. Therefore our algorithm can automatically find an optimal sequence of operations to resize the image by dynamic programming or greedy algorithm. We also extended our algorithm to indirect image resizing which can protect the aspect ratio of the dominant object in an image.

7. Partnerships and Cooperations

7.1. Regional Initiatives

Our Join Inria Tsinghua Project is located from 2004 at Tsinghua University (Beijing – China). CAD is a LIAMA Project.

8. Dissemination

8.1. Teaching - Supervision - Juries

The permanent members teach in the computer Graphics and in the Mathematics Department. Pr. Jean-Claude Paul and Pr. Jun-Hai Young give several lectures around the world every year.

9. Bibliography

Major publications by the team in recent years

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