INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Team cad

Computer Aided Design

Paris - Rocquencourt

Theme : Computational models and simulation

Activity Report

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Table of contents

1. Team

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2. Overall Objectives

2.1. Overall Objectives

Our overall objectives are to increase precision of shape modeling and processing, and more fundamentally to study mathematical and computational aspects of curves and surfaces. We thus propose to construct a new system of continuity theories, called floating-point continuities, to bridge the gap between the traditional mathematics and modern computer science. Based on the floating-point continuities and epsilon-geometry continuities approaches introduced in our recent publications, we reconsider several key geometric modeling operators.

Note that we also proposed some contributions in Computer Graphics with some Master students and with two young Tsinghua researchers, who prepared a Ph D (Weiming Dong) or a Post Doc (Bin Wang) at INRIA with us.

2.2. ε-geometry continuities

Continuities are the basic and important properties of shapes. Continuities of a surface can be addressed by the continuities of curves on the surface in arbitrary directions. Our prior works have found that epsilon-geometric continuities have some advantages over traditional parametric continuities and geometric continuities. Thus, we focus on designing curves with epsilon-geometric continuities and completely lying on a free form surface. This work will play an important role in surface blending, surface-surface intersection, surface trimming, numerical control (NC) tool path generation for machining surfaces, and so on as well.

To ensure positional continuity between the blending and base surfaces for example, linkage curves are usually first computed in the parametric domain, and then represented as the mapping of the domain curves on the base surfaces. To compute the exact curve on a free form surface in control point representation, many algorithms have been presented. However, the degrees of exact curves are considerably high, which results in computationally demanding evaluations and introduces numerical instability.

To overcome the problems of the exact, explicit representation, many approximation algorithms have been presented. To our knowledge, all presented approximation algorithms generate curves not lying completely on the surface.

If such a curve is used as a boundary curve of another surface, gaps may occur between the two surfaces, which are not acceptable in many CAD applications. In surface blending for example, if the linkage curves are not completely on the base surfaces, the blending surface and the base surfaces are not even G^0 continuous.

Novelty and originality:

We plan to study approximation algorithms that generate low degree curves lying completely on the free form surfaces. Until now, we know how to generate the initial approximate polyline, how to control the Hausdorff distance between the approximate curve and the user-specific tolerance and, finally, how to generate an $\varepsilon - G^1$ continuous curve. Our goal is to climb-up a new step in the continuity problem. We plan to study approximation algorithms that generate low degree curves lying completely on the free-form surfaces and satisfying the epsilon-continuity condition.

2.3. Floating points continuities

Up to now, almost all geometric modeling tool kits are based on traditional mathematics. They ignore the fact that computers can only represent a finite set of real numbers and simply use the formula $(a - \varepsilon < b)$ and $(b < a + \varepsilon)$ to compare whether two real numbers a and b are equal to each other or not. In the way, it becomes a very hard problem how to choose the proper value ε, i.e., the precision is often out of control in geometric modeling tool kits although few documents report such the fact. Our previous researches showed that it would require much more data for representing bodies as well. We need to build new theories from traditional mathematics such that they can well fit in with the modern computer science.

Let's consider, for example, the problem of whether two line segments intersect in the plane in Euclidean geometry. A lot of researches on this problem focus on the accuracy of the testing results by computers. Some authors find that the errors in floating-point arithmetic may make two lines intersect more than once. Exact arithmetic methods are able to make each step of computations exact and always produce correct results. However, they require much more execution time than the inaccuracy floating-point arithmetic methods, which are frequently used. Thus, one of the research directions on this problem is to improve the efficiency of the exact arithmetic. Some authors propose a technique, named double precision geometry, which could replace exact arithmetic with rounded arithmetic in computing intersections of a set of lines or line segments. Some authors give a method to reduce the cost of exact integer arithmetic with a floating-point filter and interval analysis or provide another method, named static-analysis techniques, to reduce the cost of exact integer arithmetic.

Another research direction is to investigate how to reduce the error when using fixed length floating-point arithmetic. Following this way, we have achieved a lot of important results, such as our efficient exact floating-point summation method.

Originality and novelty:

We will propose a new approach to construct a new system of continuity theories, called floating-point continuities. Based on this theory, we propose to construct NURBS surfaces satisfying the floating-point continuity condition. With this contribution, we hope to bridge the gap between the traditional mathematics used in Shape Modeling and modern computer science and act as a pioneer in this new research avenue.

2.4. Highlights

After six years, the French and Chinese partners of the CAD Project have co-signed 85 International Publications included 60 articles in the best Journals, Journal of Computer Aided Design - Elsevier or in Computer Aided Geometry Design - Elsevier, ACM Transactions on Graphics - ACM, Graphical Models - Elsevier, Pattern Recognition - Elsevier, 28 papers in the best international conferences and several Technological Transfers with Chinese and European or French Industry [1].

Today, time has come to prepare the future. So, this year, we spent efforts to develop new ideas, new cooperation with French and Chinese partners and to obtain supports from Governmental institutions as well as Industry in the two countries. It is the reason why we want to highlight this year the success of our young senior and juniors partners [2]:

[1] The complete list of publications is available on the LIAMA web site(http://liama.ia.ac.cn/wiki/_media/user:jcp:cad_pub05-10.pdf)

[2] Details and references are given in Section 5

- Prof. Xiaopeng Zhang (just promoted as a Full Professor in CASIA) for his contributions with Dr. Wujun Che in Geometry (Implicit Surfaces) published in Computer Aided Geometry Design;
- Dr. Bin Wang (Tsinghua University) and Dr. Weiming Dong (CASIA) for their top level publications in Rendering (The Visual Computer, Computer Graphics Forum,) IEEE Transactions on Visualization and Computer Graphics) and Image Synthesis (The Visual Computer, ACM Transactions on Graphics);
- And, last but not least, we want to underline the promising work in Geometry of our Ph. D. student, Kan-Le Shi who is going to join INRIA (Geometrica) for 4 Months;Dr. Dongming Yan, who has published at the prestigious ACM SIGGRAPH Conference in August 2010. He joined us in May and currently works at INRIA (ALICE) as a Post Doctor in Geometry.

3. Scientific Foundations

3.1. Historical Context

Computer Aided Design at Tsinghua University (and more generally in China), was founded by Prof. Jia-Guang Sun [3] in the 80's. At this date, the scientific challenges of the Tsinghua University CAD Institute were mainly *robustness* and *error handling* and, more recently, *Internet CAD*.

Robustness: Anything in CAD is the matter of measurements, proper metric, computational tolerances, robust implementation and validation, proper data conversion. Moreover numerical instabilities account for the majority of computational errors in commercial CAD systems.

Error handling, i.e. error prevention, error detection, error correction, and error documentation is another important challenge in CAD.

Internet CAD, i.e. collaborative CAD, language and notation, security, is a more recent research field in the Institute.

Moreover, the Institute also develops a lot of applications, supported by the Public Research Programs (MOST, NSFC, etc.).

In 2004, Prof. Jia-Guang Sun, invited Prof. Jean-Claude Paul to join Tsinghua University as a permanent Professor and they co-founded the INRIA/Tsinghua University CAD Project in LIAMA [4].

The overall objectives of this Project were to investigate a new Tsinghua/INRIA research domain: *Geometric Uncertainties*.

3.2. Geometric uncertainties: a crucial challenge for CAD

3.2.1. Geometric arrangements

Geometric arrangements are full of special cases. The most notable ones are:

- Cases of touch, overlapping, containment, etc.;
- Cases of parallelism, perpendicularity, coincidence, etc.;
- Cases 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.

[3] Prof. Jia-Guang Sun is a Member of the Chinese Academy of Engineering. He is the Vice President of NSF China and the Director of the School of Science and Technology at Tsinghua University.

[4] From 2005, Prof. Jun-Hai Yong, an outstanding young researcher, who was appointed as a Professor at Tsinghua in 2005 and succeeded to Prof. Jia-Guang Sun as the new Director of the Tsinghua CAD Institute, is the Chinese leader of the CAD Project.

In just about any code that deals with geometry, the number of special cases is significantly larger than the general ones.

3.2.2. Data explosion

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 may result in an explosion of control points;
- Excess data on input may get magnified further to fill available memory;
- Improper data structures, e.g. arrays of fixed size holding very little data; and non-compacted databases used for further processing.

3.2.3. Geometric beautification

Although CAD processes are supposed to produce valid and 'made to order' models, the reality is that most (if not all) models are rough and require post-processing, i.e. beautification.

Some of the most frequently needed tasks are:

- Removing unwanted edges, corners, cracks, etc.;
- Removing bumps, oscillations, curvature extremes, etc.;
- Healing incorrect models, e.g. removing holes in triangulations;
- Smoothing, fairing, re-shaping, etc.

The other relevant issue is to find the right mathematical formulation for geometric beautification, e.g. what is the quantitative measure of flatness, curviness, smoothly changing, fairness, etc.
We will present in Section 5 tour main contributions in this research domain.

4. Application Domains

4.1. Application Domains

Geometry Modeling and Computing has a dramatic impact on the way. Design and Engineering's work: Sketch design, Aerodynamics simulations, Mechanical Engineering, Manufacturing, Crash test, Pilot training, Marketing, Maintenance operation, etc. Today, all these operations are based on a mathematical ad computational representation of surfaces and volumes and require a high level of precision.

5. Software

5.1. T-GEMS

Participant: Hui Zhang [correspondant].

We (Dr. Hui Zhang) contribute to T-GEMS, a Geometry Kernel for curves and surfaces developed by the Tsinghua CAD Institute. This code is not an open-source code.

6. New Results

6.1. Main contributions since November 2008

The CAD project mainly addressed the three problems mentioned in Section 3. We briefly present results here, because we consider that we proved our success with a lot of published papers. On the other hand, we like to underline in this Section (5.1.2.) the new challenges we want to develop in the two next years, both in Geometry and in Computer Graphics.

6.1.1. Geometric arrangements

We have published several papers to compute the minimum distance between two Bézier curves, between a point and clamped B-spline surface, between a point and a NURBS curve, computing the Hausdorff distance between two B-spline curves [12], [23], [32], [38], [39], [40]. In [38] for example, a sweeping sphere clipping method is presented for computing the minimum distance between two Bézier curves. The sweeping sphere is constructed by rolling a sphere with its center point along a curve. The initial radius of the sweeping sphere can be set as the minimum distance between an end point and the other curve. The nearest point on a curve must be contained in the sweeping sphere along the other curve, and all of the parts outside the sweeping sphere can be eliminated. A simple sufficient condition when the nearest point is one of the two end points of a curve is provided, which turns the curve/curve case into a point/curve case and leads to higher efficiency. Examples are shown to illustrate efficiency and robustness of the new method. We also study other operations such as approximate computation of curves on B-spline surfaces [25], [46], [48], cubic B-spline curve by curve unclamping [11], point projection on surfaces, intersections between surfaces [25]. Length, area and volume are important mass properties of geometric objects that need to be computed frequently in many medical, biological and industrial applications [23], [16], [15]. In [17], for example, we study the particular problem of estimating the surface area of a digitized three-dimensional (3D) object in a volumetric representation.

6.1.2. Data explosion

Non Uniform B-spline surfaces (NURBS) are a class of parametric surfaces that are commonly used in geometry modeling. With NURBS, the designer can create curves and surfaces with control points or weights very easily. A serious weakness with NURBS is that NURBS control points must lay topologically in a rectangular grid. This means that typically, a large number of NURBS control points serve no purpose other than to satisfy topological constraints. And inserting extra control points is not possible without propagating an entire row or column of control points. Then, a typical NURBS surface model has a large percentage of superfluous control points that significantly interfere with the design process, Superfluous control points are a serious nuisance for designers, not merely because they require the designer to deal with more data, but also because they can introduce unwanted ripples in the surface Designers can waste dozens of hours on models such as this in tweaking the NURBS control points while attempting to remove unwanted ripples. Since several years, we work on a new mathematical formulation of B-Spline surfaces that are a generalization of NURBS and allow the number of control points to be reduced significantly. We also proposed an algorithm for reducing control points in lofted surface interpolation to rows of data points. The proposed algorithm in [22] can guarantee to obtain the lofted surface and avoid to determining appropriate common knot vector. Several experimental results demonstrate the usability and quality of the proposed method.

6.1.3. Geometric beautification

Continuities are the basic and important properties of shapes. Continuities of a surface can be addressed by the continuities of curves on the surface in arbitrary directions. Our prior works have founded that epsilon-geometric continuities have some advantages over traditional parametric continuities and geometric continuities. Thus, we have focused on designing curves with epsilon-geometric continuities and completely lying on a free form surface. Our work will play an important role in surface blending, surface-surface intersection, surface trimming, numerical control and so on as well. Until now, we know how to generate the initial approximate polyline, how to control the Hausdorff distance between the approximate curve and the user-specific tolerance and, finally, how to generate a $\epsilon - G^1$ continuous curve [19]. Our goal is to climb-up a new step in the continuity problem. We plan to study approximation algorithms that generate low degree curves lying completely on the free-form surfaces and satisfying the epsilon-continuity condition. We have presented some G-continuity algorithms that allow to constructing some specific curves, such as G^1 [19]. In [20], we have proposed a method of G^n blending multiple parametric surfaces in polar coordinates. To extend its compatibility, we also propose a method of converting polar coordinate blending surface into NURBS patches. One application of this technique is to fill N-sided holes.

Parametric and implicit equations are two basic techniques used to produce 3D curved surfaces. By far, parametric representation dominates most common analytic representations for curves and surfaces in computer-aided geometric modeling, benefiting from their convenient analysis and expression of their geometric shape and features. For a parametric surface, each surface patch must possess its corresponding 2D parametric domain. It is a non-trivial task to construct proper and global parameterizations for a complex shape. They cannot be directly applied to non-parametric surfaces, i.e. implicit surfaces. In contrast to traditional parametric surfaces, implicit surfaces are independent of parameterizations. We have developed a mathematical method to analyze and compute the lines of curvature and their differential geometry defined on an implicit surface.

6.2. New research Objectives

These two last years, we also decided to deal with new problems in *Geometry*. Moreover, we have included *Computer Graphics* as a new research domain for the Project in the future years. Note that all the topics mentioned have been submitted and accepted as publications and as governmental or industrial Projects. Moreover, they will be enforced by stronger cooperation with prestigious teams in the world.

6.2.1. Geometry: new challenges

6.2.1.1. Floating point Continuity

We like to address the problem of Numerical instabilities in Geometry Modeling. Up to now, almost all geometric modeling tool kits are based on traditional mathematics. They ignore the fact that computers can only represent a finite set of real numbers and simply use the formula $(a - \epsilon < b)$ and $(b < a + \epsilon)$ to compare whether two real numbers a and b are equal to each other or not. In the way, it becomes a very hard problem how to choose the proper value ϵ, i.e., the precision is often out of control in geometric modeling tool kits although few documents report such the fact. Our previous researches showed that it would require much more data for representing bodies as well. We need to build new theories from traditional mathematics such that they can well fit in with the modern computer science.

Let's consider, for example, the problem of whether two line segments intersect in the plane in Euclidean geometry. A lot of researches on this problem focus on the accuracy of the testing results by computers. Some authors find that the errors in floating-point arithmetic may make two lines intersect more than once. Exact arithmetic methods are able to make each step of computations exact and always produce correct results. However, they require much more execution time than the inaccuracy floating-point arithmetic methods, which are frequently used. Thus, one of the research directions on this problem is to improve the efficiency of the exact arithmetic. Some authors propose a technique, named double precision geometry, which could replace exact arithmetic with rounded arithmetic in computing intersections of a set of lines or line segments. Some authors [5] give a method to reduce the cost of exact integer arithmetic with a floating-point filter and interval analysis or provide another method, named static-analysis techniques, to reduce the cost of exact integer arithmetic.

Another research direction is to investigate how to reduce the error when using fixed length floating-point arithmetic. Following this way, we have achieved a lot of important results [47], such as our efficient exact floating-point summation method. In the future, we will propose a new approach to construct a new system of continuity theories, called floating-point continuities. Based on this theory, we propose to construct NURBS

[5] Zhu, Y.-K.: Yong, J.-H., Zheng, G.-Q.: A new distillation algorithm for floating-point summation. SIAM J. Sci. Comput. 2005, 26 (6): 2066-2078.

surfaces satisfying the floating-point continuity condition. With this contribution, we hope to bridge the gap between the traditional mathematics used in Shape Modeling and modern computer science and act as a pioneer in this new research avenue.

Prof. Jun-Hai Yong is the leader of this Project. He will work in cooperation with INPG and Joseph Fourrier (Grenoble), ENS Cachan (France), Professors and students, in the context of the ANR/NSF-SHAN Project. With the agreement of the Steering Committee, Prof. Xiaopeng Zhang and Dr. Wujun Che [6] will work on this project in the context of the LIAMA CAD Project.

6.2.1.2. Various Knot B-spline surfaces

We want to provide a new formulation of B-spline surfaces that allow both the geometric beautification of Geometric Models and the data explosion control. Our approach is a generalization of standard B-spline surface (the various-knot B-spline surface). It benefits the transition between sharp and rounded features; it achieves G^n internal continuity and on the boundary; and it can greatly reduces the control points of a blending surface.

We propose the various-knot B-spline surface as a generalization of standard B-spline surface. This generalization benefits the transition between sharp and rounded features; it achieves G^n internal continuity and on the boundary; and it can greatly reduces the control points of a blending surface.The following figure is an example of periodic various-knot B-spline surface, transiting a sharp edge to the rounded feature. You may find that the control points are so few and simple. And the transition is not artificial. Besides, we can easily control the continuity between the various-knot B-spline surface and the specified two boundary surfaces.

In the definition of standard B-spline surface, knot vectors U and V are constants. This leads the fact that in u and v direction, the continuity feature of the surface is preserved. In our definition about various-knot B-spline, we consider U and V as the function on v and u, respectively. That is,

$$\begin{aligned} S(u,v) &= \sum_{i=0}^{n-1}\sum_{j-1}^{m-1} N_{i,p}^{U(v)}(u)N_{j,q}^{V(u)}(v)P_{ij} \\ U(v) &= \{u_0(v),u_1(v),...,u_{r-1}(v)\}, V(u)=\{v_0(u),v_1(u),...,v_{s-1}(u)\} \end{aligned} \tag{1}$$

According to this definition, in the parametric domain, you can find that A is not continuous (see Figure 1 and note the multiplicity leads the discontinuity on A). But on the top edge, you may find the surface should be continuous, since there is no multiplicity. The mechanism preserves the continuity and smoothness of the entire surface.

The evaluation of the various-knot B-spline surface is simple. We only need to compute the U and V knot vector according to the specified u and v locally and apply the evaluation method of B-spline surface.

This work will be developed in the context of the ANR/NSFC Program in cooperation with INRIA Sophia Antipolis (Geometrica).

6.2.1.3. Finite Elements Analysis and Geometry

Current engineering design practice in industry employs 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 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

[6] Prof. Xiaopeng Zhang is a Professor at CASIA. He was a Post Doctor at INRIA Nancy-Grand Est from 2003 to 2004. He worked with Prof. Jean-Claude Paul in Geometry (Implicit surfaces) and he and his Ph. D. and Master students will focus their research activities on the new Geometry Challenges presented here. Dr. Wujun Che is an Assistant Professor at CASIA. He was a Post Doctor at Tsinghua University with Prof. Jean-Claude Paul. They currently are members of LIAMA Greenlab Project.

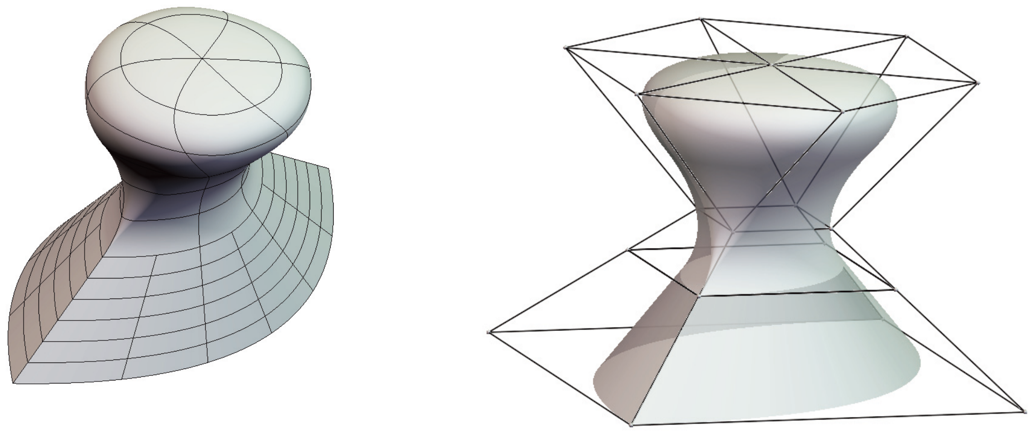

Figure 1. You may find that the control points are so few and simple. And the transition is unartificial. Besides, we can easily control the continuity between the various-knot B-spline surface and the specified two boundary surfaces.

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 at evaluation how such approach deals with simulation accuracy/convergence according to CAD definition (quality/size of patches used to define the 3D shape).

Another idea is to unify the formalization of best approximation of PDE and best sampling/meshing into a single general formulation and study its mathematical properties.

Prof. Jean-Claude Paul will work on these two approaches. The first one will be developed in the context of the Systematic CSDL Program and with the technical support of Dassault Aviation and EADS. Prof. Jean-Claude Paul and Dr. Dongming Yan will develop the second approach with Dr. Bruno Lévy (INRIA Alice) his ERC research Program and in the context of his ERC and ANR Program.

6.2.2. Computer Graphics

6.2.2.1. Post Processing

Image synthesis is a very effective way in image acquisition and editing. Image synthesis plays an important role in the post-processing computer animations and movies. In this context, the goal of our work in this area is to develop new image synthesis methods [41], [44], [45], [43], [42], by analyzing the content of the source image (color, lighting, texture and other necessary features), which should be integrated into energy functions. Optimization algorithm will be constructed by studying the connections between image content analysis and the synthesis process. Different algorithms will be studied according to the specific visual effects. The problem will be studied under different directions:

- Feature-based texture synthesis. We will study how to integrate local and global features of the texture examples into the synthesis process. The results are expected to inherit the features of the examples, or appear some special patterns designed by users;
- Content-aware photo/video editing. We will develop new tools to edit the appearances of digital photos or videos. We will focus on how to adjust the colors, lightings, and textures in the examples;
- Painterly stylization of image/video. We will study new algorithms to convert an image or video to artistic style (oil painting, watercolor, etc.). We will focus on the efficient stylization of high-resolution images and videos. We will try to simulate the real painting process in our algorithms.

Dr. Weiming Dong will develop this work in cooperation with INRIA Bordeaux (IPARLA), Sony research (Dr. Ning Zhou) and MIT (Frédo Durand). Note that several Chinese Governmental and Industrial Programs (Shanghai Cartoons and Movies Service Platform) will support this promising work. Moreover, Prof. Zhiyi Zhang [7] (CASIA) will give his technical support to Dr. Weiming Dong's Masters students.

6.2.2.2. Photorealistic rendering

First, we propose to improve the photon mapping based method we proposed in [26]. The photon mapping is a consistent rendering technique in the sense that it converges to the correct physical result as the number of photons and bounces increases. The idea of photon mapping is to trace photons throughout the scene, and to cache the hit points in a data structure called the photon map. Radiance is then reconstructed in the rendering pass using photon density estimation. We coupled this technique with an image space approach, in which the scene geometry is represented by a depth image, and ray-geometry intersections required by photon tracing are computed directly using the depth information. Our method is capable of computing a lot of illumination effects Moreover, dynamic scenes and dynamic lightings are supported without preprocessing of scene geometry or light transfer.

We also want to improve the computation of subsurface scattering effects of light as well as more complex lighting properties (diffraction?). Scattering of light is a complex phenomenon that occurs in many materials such as jade, marble and human skin. It plays an important role in the realism of rendered scenes, but unfortunately is also challenging to simulate. In translucent objects, the outgoing radiance at each point on the surface depends on three factors: Incoming radiance at all points on the surface, the path followed by the light inside the object as well as the optical properties along this path. Accurately rendering a translucent object can take several hours with off-line physical simulation. The *diffusion equation* [8] fully describes subsurface multiple-scattering effects in translucent objects, including heterogeneous materials. We develop the first method to solve the diffusion equation, in real-time, on objects of arbitrary shapes with heterogeneous materials [21].

Prof. Jean-Claude Paul developed this topic at INRIA (ISA) several years ago. Now, Dr. Bin Wang [9], who was a Ph. D. student at Tsinghua, then a Post Doctor at INRIA (ISA/ALICE) for two years, is an Assistant Professor at Tsinghua University. Because of the successful work of Dr. Bin Wang and the very high interest of Tsinghua students for this field, we propose to introduce this "new" topic in our CAD Project. This work is supported by Chinese governmental grants and will be developed in cooperation with INRIA - Rhones Alpes (ARTIS).

7. Contracts and Grants with Industry

7.1. Contracts with Industry

We contributed to some industrial applications, mainly:

- Aircraft industry: Design of wings (with EADS)

[7] Prof. Zhiyi Zhang is a famous Movie Maker who leads a large Computer Animation group in CASIA. He obtained several awards in China and recently in France.

[8] ISHIMARU A.: Wave Propagation and Scattering in Random Media. Academic Press, 1978.

[9] Note also that Dr. Bin Wang is the scientific delegate in China of System@tic (Technological Center of Ile de France).

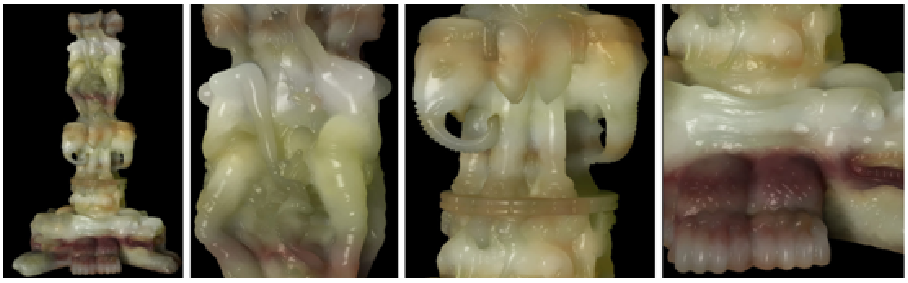

Figure 2. Rendering results at 22 frames per-second of the Stanford Thai Statue (157 K triangles) with our system.

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.

Figure 3. Winglets improve efficiency of fixed-wing aircraft.

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 is 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 these data could be used to help gather triangles by geometric entities and then to help compute the exact surfaces. Depending on the programming method used in the CAM software, these data would be more or less accepted as valid. Therefore, they should not be the only criterion to identify 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. In this case, the reverse engineering should be straightforward with:

- The help of the additional data;
- The accuracy of the generated triangles. If it is the machining tolerance, then the triangles that represent a cylinder will have a rope error of t. The vertices of the triangles are on the exact cylinder surface. The normals at the vertices are those of the cylinder.

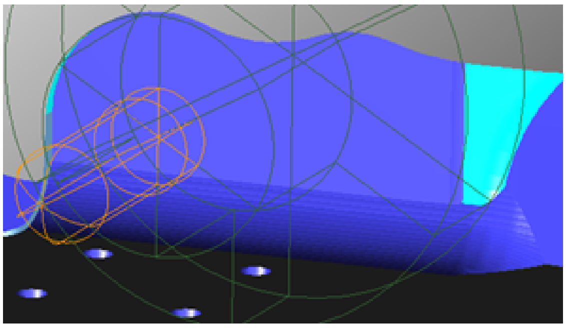

Figure 4. Minimizing the number of surfaces.

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:

- Superior to the CAM tolerance used to compute the tool path. This tolerance usually creates small surface variations on the machined solid, which result on small ridges and cracks on the triangles created by the simulation;
- Superior to the simulation tolerance;
- The reverse engineering process is expected to minimize the number of surfaces. For example, (figure) the spherical tool sweeps a cylinders and a torus. The best would be to find them back;
- The quality criterion is the geometric model accuracy. However, the model must be suitable for further work on it with the current CAM software, even to the detriment of the model exactness. Slight alteration of the model would be considered to suppress small residual pieces of material at the end of the simulation.

- CSDL System@tic: Geometry and FEM (with Dassault Aviation) 201

  Finite Elements Analysis and Geometry (Please see Section 5).

8. Other Grants and Activities

8.1. National Initiatives

We do not mention here the grants obtained by researchers from Tsinghua University and CASIA who want to join the Project.

- ANR (France) / NSF (China): 2010-2012

  Geometry Continuity
- NSF (China)

  Geometry Modeling
- MOST Program 973 (China): 2009-2011

  Geometry precision control

9. Dissemination

9.1. Journal Editors and Conference Program Committee Members

- Prof. Jun-Hai Yong and Prof. Jean-Claude Paul are Co-editors, Committee Members or Reviewers of several International Journal (Journal of CAD, Graphical Models, Computers and Graphics,) and several international conferences (SMI, SGP, etc.).

9.2. Teaching

- Prof. Jun-Hai Yong, Prof. Jean-Claude Paul and Dr. Hui Zhang teach at Tsinghua University (Bachelor and Master Degree in Applied Mathematics and Computer Science). Dr. Hui Zhang is a Vice Director of the School of Software (Tsinghua University)

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