INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team Tsinghua-CAD

Computer Aided Design

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THEME COG

Activity Report

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Tsinghua-CAD is a research project shared by INRIA and Tsinghua University. It is a research group of the Institute of Computer Aided Design at Tsinghua University.

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2. Overall Objectives

2.1. Overall Objectives

Our research field is focused on Geometry of curves and surfaces, more precisely on NURBS (Non Uniform Rational B-Splines), a class of surfaces that is widely used in CAD Systems and Computer Graphics Applications. This mathematical representation is very practical for Geometry Design. The designer can create curves with control points or weights very easily. Moreover, parametric surfaces allow attaching physical properties to the geometry (in the parametric space). However, many computation problems cannot be solved in a closed mathematical form with NURBS.

Our overall objectives are to solve some challenging computational problems with parametric surfaces, and more fundamentally, to find more efficient mathematical representations of 3D objects.

3. Scientific Foundations

3.1. Document Description and Metadata

In Geometry Modeling, shapes are described in term of Parametric Surfaces. The pioneering work in this domain was the theory of Bézier curves and surfaces (theory of polynomial curves and surfaces in Bernstein form), later combined with B-spline methods. To-day, Non-Uniform Rational B-Spline (NURBS) have become the standard curves and surfaces description in the field of CAD. Differential Geometry is also an important scientific foundation for Geometry Modeling. Differential geometry is based largely of the pioneering work of L. Euler (1707-1783), C. Monge (1746-1818) and C.F. Gauss (1777-1855). One of their concerns was the description of local curves and surface properties such as curvature. These concepts are also of interest in modern computer-aided geometry design. The main tool for the development of general results is the use of local coordinate systems, in term of which geometric properties are easily described and studied [21].

In contrast to traditional parametric surfaces, implicit surfaces are independent of parameterizations. They can easily describe smooth and intricate shapes, and possess closure under many geometric operations. Implicit surfaces are finding use in a growing number of geometric modeling and graphics applications. Because of the advantages of implicit representation, people are now attaching more and more importance to modeling with implicit surfaces. However, managing complex models remains difficult compared with traditional parametric representation. One main reason is that it is more difficult to capture the geometric features of an implicit surface than those of a parametric one. Because of the convenience of explicit formulae of geometric attributes for computation and analysis, it is valuable to derive the corresponding formulae for implicit surfaces. However, the formulae of geometric attributes for implicit surfaces, such as Gaussian curvature, are not developed so well as those on parametric surfaces, and they are harder to find in the literature [22].

4. Application Domains

4.1. Application Domains

CAD Systems have a dramatic impact to day on the way designers and engineer's work. In the industry: sketch and design, marketing, project review, pilot training, mechanical engineering, aero dynamic simulation, ergonomic studies, virtual reality, or maintenance operations.

All these works are based on numerical geometric models and simulations. Note that the PLM (Product Life Management) concept in industry requirement needs to handle the same geometric models from the creation to the experience.

Figure 1.

5. Software

5.1. TiGems

TiGems: TiGems is a Geometry Modeling Library developed by the National Research Center for Development Software at Tsinghua University.

6. New Results

6.1. Curves and Surfaces

6.1.1. Approximate computation of curves on B-spline surfaces

Keywords: *Approximation*, *B-spline*, *Curve approximations*, *Curves on surfaces*.

Participants: Yi-Jun Yang, Song Cao, Jun-Hai Yong ,, Hui Zhanga, Jean-Claude Paul, Jia-Guang Sun, He-Jin Gu.

Curves on surfaces play an important role in computer-aided geometric design. Because of the considerably high degree of exact curves on surfaces, approximation algorithms are preferred in CAD systems. To approximate the exact curve with a reasonably low degree curve which also lies completely on the B-spline surface, an algorithm is presented in this paper. The Hausdorff distance between the approximate curve and the exact curve is controlled under the user-specified distance tolerance. The approximate curve is $\epsilon_T G^1$ continuous, where ϵ_T is the user-specified angle tolerance. Examples are given to show the performance of our algorithm [5][8].

6.1.2. Computing the minimum distance between a point and a NURBS curve

Keywords: *NURBS curve*, *Newton's method*, *Point projection*, *Root isolation*, *Subdivision*.

Participants: Xiao-Diao Chen, Wenping Wang, Jun-Hai Yong, Guozhao Wang, Jean-Claude Paul, Gang Xu.

A new method is presented for computing the minimum distance between a point and a NURBS curve. It utilizes a circular clipping technique to eliminate the curve parts outside a circle with the test point as its center point. The radius of the elimination circle becomes smaller and smaller during the subdivision process. A simple condition for terminating the subdivision process is provided, which leads to very few subdivision steps in the new method. Examples are shown to illustrate the efficiency and robustness of the new method [1].

6.1.3. A numerically stable fragile watermarking scheme for authenticating 3D models

Keywords: *Error prevention*, *Fragile watermarking*, *Mesh authentication*, *Tamper detection*.

Participants: Wei-Bo Wang, Guo-Qin Zheng, Jun-Hai Yong, He-Jin Gu.

This paper analyzes the numerically instable problem in the current 3D fragile watermarking schemes. Some existing fragile watermarking schemes apply the floating-point arithmetic to embed the watermarks. However, these schemes fail to work properly due to the numerically instable problem, which is common in the floating-point arithmetic. This paper proposes a numerically stable fragile watermarking scheme. The scheme views the mantissa part of the floating-point number as an unsigned integer and operates on it by the bit XOR operator. Since there is no numerical problem in the bit operation, this scheme is numerically stable. The scheme can control the watermark strength through changing the embedding parameters. This paper further discusses selecting appropriate embedding parameters to achieve good performance in terms of the perceptual invisibility and the ability to detect unauthorized attacks on the 3D models. The experimental results show that the proposed public scheme could detect attacks such as adding noise, adding/deleting faces, inserting/removing vertices, etc. The comparisons with the existing fragile schemes show that this scheme is easier to implement and use [4].

6.1.4. Computing the Minimum Distance between Two Planar Algebraic Curves

Keywords: *Minimum distance*, *Off set method*, *Planar algebraic curves*.

Participants: Xiao-Diao Chen, Jun-Hai Yong, Guozhao Wang.

Through geometric observation, it is found that the nearest point on a curve is a tangent point between the curve and an off set curve of the other curve. Based on this observation, an off set method is presented for computing the minimum distance between two planar algebraic curves. The new method is geometrically instructive, and can be used for computing the minimum distance between an algebraic curve and a parametric one on the same plane. For planar quadratic curves, the degree of the resulting univariate polynomial equation by our method is much lower than that of the equations in previous comparable methods, which may lead to lower computation complexity or higher robustness of the solutions [10].

6.1.5. Computing the minimum distance between two Bézier curves

Keywords: *Bézier curve*, *Minimum distance*, *Sweeping sphere clipping method*.

Participants: Linqiang Chen, Yigang Wang, Gang Xu, Jun-Hai Yong, Jean-Claude Paul.

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 another 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 [9].

6.1.6. Progressive Interpolation using Loop Subdivision Surfaces

Keywords: *Bézier curve*, *Minimum distance*, *Sweeping sphere clipping method*.

Participants: Fuhua Cheng, Fengtao Fan, Shuhua Lai, Conglin Huang, Jiaxi Wang, Jun-Hai Yong.

A new method for constructing interpolating Loop subdivision surfaces is presented. The new method is an extension of the progressive interpolation technique for B-splines. Given a triangular mesh M, the idea is to iteratively upgrade the vertices of M to generate a new control mesh $\overline{M}$ such that limit surface of $\overline{M}$ interpolates M. It can be shown that the iterative process is convergent for Loop subdivision surfaces. Hence, the method is well defined. The new method has the advantages of both a local method and a global method, i.e., it can handle meshes of any size and any topology while generating smooth interpolating subdivision surfaces that faithfully resemble the shape of the given meshes [11], [18].

6.1.7. Dynamic PDE parametric curves

Keywords: *Convergence*, *Finite difference method*, *Interpolation*, *PDE curves*.

Participants: Xu-Zheng Liu, Xia Cui, Guo-Qin Zheng, Jun-Hai Yong, Jia-Guang Sun.

Dynamic partial differential equation (PDE) parametric curves which can be expressed as a coupled system of two hyperbolic equations are developed. In curve design, dynamic PDE parametric curves can be modified intuitively and are more flexible than ordinary differential equation (ODE) curves. The calculation of dynamic PDE parametric curves must recur to numerical methods and a three-level finite difference scheme is proposed. Approximation and stability properties for the scheme are proved and convergence property is derived. An example of interpolating PDE curves is presented as an application of dynamic PDE parametric curves [14].

6.1.8. Identification of Sections from Engineering Drawings Based on Evidence Theory

Keywords: *Engineering drawing*, *Evidence theory*, *Orthographic projection*, *Sectional view*, *Solid reconstruction*.

Participants: Jie-Hui Gong, Hui Zhang, Bin Jiang, Jia-Guang Sun.

View identification is the basal process for solid reconstruction from engineering drawings. A new method is presented to label various views from a section-involved drawing and identify geometric planes through the object at which the sections are to be located. In the approach, a graph representation is developed for describing multiple relationships among various views in the 2D drawing space, and a reasoning technique based on evidence theory is implemented to validate view relations that are used to fold views and sections in the 3D object space. This is the first automated approach which can handle multiple sections in diverse arrangements, especially accommodating the aligned section for the first time. Experimental results are given to show that the proposed solution makes a breakthrough in the field and builds a promising basis for further expansibility, although it is not a complete one [19] [31].

6.1.9. Lines of curvature and umbilical points for implicit surfaces

Keywords: *Curvature*, *Gaussian curvature*, *Implicit surface*, *Line of curvature*, *Mean curvature*, *Torsion*, *Umbilical point*.

Participants: Wujun Che, Jean-Claude Paul, Xiaopeng Zhang.

We develop a method to analyze and compute the lines of curvature and their differential geometry defined on implicit surfaces. With our technique, we can explicitly obtain the analytic formulae of the associated geometric attributes of an implicit surface, e.g. torsion of a line of curvature and Gaussian curvature. Additionally, it can be used to directly derive the closed formulae of principal directions and corresponding principal curvature of an implicit surface. We also present a novel criterion for nonumbilical points and umbilical points on an implicit surface [23].

6.1.10. A counterexample on point inversion and projection for NURBS curve

Keywords: *Point inversion*.

Participant: Xiao-Diao Chen.

In this work, we present a counterexample on point inversion and projection for NURBS curve [24].

6.1.11. Adaptive geometry compression based on 4-point interpolatory subdivision schemes with labels

Keywords: *4-point subdivision*, *geometry compression*, *high-speed curve generation*, *in- terpolatory subdivision*, *subdivision scheme*.

Participants: Hui Zhang, Jun-Hai Yong, Jean-Claude Paul.

We propose an adaptive geometry compression method based on 4-point interpolatory subdivision schemes. It can work on digital curves of arbitrary dimensions. With the geometry compression method, a digital curve is adaptively compressed into several segments with different compression levels. Each segment is a 4-point subdivision curve with a subdivision step. In the meantime, we provide high-speed 4-point interpolatory subdivision curve generation methods for efficiently decompressing the compressed data. In the decompression methods, we consider both the open curve case and the closed curve case. For an arbitrary positive integer k, formulae of the number of the resultant control points of an open or closed 4-point subdivision curve after k subdivision steps are provided. The time complexity of the new approaches are $O(n)$, where n is the number of the points in the given digital curve. Examples are provided as well to illustrate the efficiency of the proposed approaches [49].

6.1.12. A Survey on Solid Reconstruction from Engineering Drawings

Keywords: *Boundary representation*, *Constructive solid geometry*, *Orthographic views*, *Solid reconstruction*.

Participants: Jie-Hui Gong, Hui Zhang.

Solid reconstruction from engineering drawings is one of the efficient technologies to product solid models, which has become one of the important research topics in both computer graphics and artificial intelligence. The problem of solid reconstruction from engineering drawings is captured. The taxonomy for solid reconstruction techniques is presented with the typical algorithms reviewed. After comparing the application areas of the algorithms, the open research issues are analyzed. Finally, the future work in the research field is also pointed out [32].

6.1.13. An offset algorithm for polyline curves

Keywords: *Clipping algorithm*, *Offset curve*, *Polyline curve*.

Participants: Xu-Zheng Liu, Jun-Hai Yong.

Polyline curves which are composed of line segments and arcs are widely used in engineering applications. In this paper, a novel offset algorithm for polyline curves is proposed. The offset algorithm comprises three steps. Firstly, the offsets of all the segments of polyline curves are calculated. Then all the offsets are trimmed or joined to build polyline curves that are called untrimmed offset curves. Finally, a clipping algorithm is applied to the untrimmed offset curves to yield the final results. The offset algorithm can deal with polyline curves that are self-intersection, overlapping or containing small arcs. The reliability of the new algorithm is verified by a great number of examples [40].

6.1.14. Constrained Interpolation with Biarcs

Keywords: *Constrained interpolation*, *biarc*, *straight line constraint*.

Participants: Xu-Zheng Liu, Jun-Hai Yong.

An algorithm to construct biarcs that not only match the interpolation requirement of the point positions and tangent vectors but also lie on one side of the constraint line is proposed. For C-type biarc interpolation with the line constraint, firstly twelve inequalities in total are provided according to different position relationships between the constraint line and the interpolation requirement. These inequalities are used to check if biarcs lie on one side of the constraint line. If there exist many biarcs satisfying both the interpolation requirement and the line constraint, the optimal biarc can be obtained by solving a minimum problem1 Otherwise, one ext ra point is added to make it possible to obtain biarcs. For S-type biarc interpolation with the line constraint, some results are also listed [41] [43].

6.1.15. Standardization of Rational Bézier Surfaces

Keywords: *Möbius transformation*, *Rational Bézier Surfaces*, *quadratic reparameterization*.

Participants: Yi-Jun Yang, Jun-Hai Yong.

The sufficient and necessary condition for the existence of linear Möbius transformations that can standardize the rational Bézier surfaces is given based on Möbius reparameterization theorem. To obtain the standard form of an arbitrary cubic rational Bézier surface, we then present a quadratic reparameterization algorithm to reparameterize the surface so that all the corner weights of the surface are equal to one. Examples are included to show the performance of the new method [44].

6.1.16. Best uniform approximation to a class of rational functions

Keywords: *Best approximation*, *Chebyshev polynomial*, *Uniform norm*.

Participants: Zhitong Zheng, Jun-Hai Yong.

We explicitly determine the best uniform polynomial approximation $p*_{n-1}$ to a class of rational functions of the form $1/(x-c)^2 + K(a,b,c,n)/(x-c)$ on $[a,b]$ represented by their Chebyshev expansion, where a, b, and c are real numbers, $n-1$ denotes the degree of the best approximating polynomial, and K is a constant determined by a, b, c, and n. Our result is based on the explicit determination of a phase angle η in the representation of the approximation error by a trigonometric function. Moreover, we formulate an ansatz which offers a heuristic strategies to determine the best approximating polynomial to a function represented by its Chebyshev expansion. Combined with the phase angle method, this ansatz can be used to find the best uniform approximation to some more functions [52].

6.1.17. Reducing control points in lofted B-spline surface interpolation using common knot vector determination

Keywords: *Approximate energy minimization*, *B-spline curve compatibility*, *B-spline surface interpolation*, *Surface lofting*.

Participants: Wen-Ke Wang, Hui Zhang, Jun-Hai Yong, Jean-Claude Paul, Jia-Guang Sun.

A new algorithm for reducing control points in lofted surface interpolation to rows of data points is presented. The proposed algorithm can guarantee to obtain the lofted surface and avoid to determine appropriate common knot vector. Given a set of points and their precomputed parameterization, a necessary and sufficient condition is proposed to determine the existence of interpolating B-spline curves defined on a given knot vector. Based on this condition, we first properly constructs a common knot vector. Then we efficiently calculate a set of interpolating smooth B-spline curves defined on the common knot vector by approximate energy minimization. Using this method, less control points are employed while maintaining visually pleasing shape of the lofted surface. Several experimental results demonstrate the usability and quality of the proposed method [3].

6.1.18. Intersection testing between an ellipsoid and an algebraic surface

Keywords: *Intersection testing*, *algebraic surface*, *ellipsoid*, *tangent point method*.

Participants: Xiao-Diao Chen, Jun-Hai Yong, Jean-Claude Paul, Jia-Guang Sun.

In this work, we develop a new method on the intersection testing problem between an ellipsoid and an algebraic surface. In the new method, the testing problem is turned into a new testing problem whether a univariate polynomial has a positive or negative real root, which can be more easily solved. Examples are shown to illustrate the robustness and efficiency of the new method [25].

6.1.19. Converting hybrid wire-frames to B-rep models

Keywords: *2-manifold*, *Graph theory*, *Model conversion*, *Möbius rule*, *Solid reconstruction*.

Participants: Jie-Hui Gong, Hui Zhang.

Solid reconstruction from engineering drawings is one of the efficient technologies to product solid models. The B-rep oriented approach provides a practical way for reconstructing a wide range of objects. However, its major limitation is the computational complexity involved in the search for all valid faces from the intermediate wire-frame, especially for objects with complicated face topologies. We propose an algorithm to convert the hybrid wire-frame to the final B-rep model by extracting all the rest faces of planes based on graph theory. The entities lying on the same planar surface are first collected in a plane graph. After all the cycles are traced in a simplified edge-adjacency matrix of the graph, the face loops of the plane are formed by testing loop containment and assigning loop directions. Finally, the B-rep model is constructed by sewing all the plane faces based on the Möbius rule. The method can efficiently construct 2-manifold objects with a variety of face topologies, which is illustrated by results of implementation [34].

6.1.20. Efficient Exact Arithmetic over Constructive Reals

Participants: Yong Li, Jun-Hai Yong.

We describe a computing method of the computable (or constructive) real numbers based on analysis of expressions. This method take precision estimate into account in order to get a better algorithm than Ménissier-Morain' s method, which is also based on the representation of constructive reals. We solve two problems which appear in exact real arithmetic based on the representation of constructive reals. First, by balancing every item' s precision in the expression, we can avoid unnecessary precision growth. Second, by distributing different weights to different operations, we can make sure that complex operations do not waste much time when to compute the whole expression. In these ways, we finally get a more efficient and proper method than prior implementations [36].

6.1.21. Iterative Methods for Visualization of Implicit Surfaces on GPU

Keywords: *Implicit surfaces*, *ray casting*.

Participants: Rodrigo de Toledo, Bruno Lévy, Jean-Claude Paul.

The ray-casting of implicit surfaces on GPU has been explored in the last few years. However, until recently, they were restricted to second degree (quadrics). We present an iterative solution to ray cast cubics and quartics on GPU. Our solution targets efficient implementation, obtaining interactive rendering for thousands of surfaces per frame. We have given special attention to torus rendering since it is a useful shape for multiple CAD models. We have tested four different iterative methods, including a novel one, comparing them with classical tessellation solution [54][7].

6.1.22. Geometry Textures

Keywords: *Geometry texture*, *Mesostructure*.

Participants: Rodrigo de Toledo, Bin Wang, Bruno Lévy.

In highly tessellated models, triangles are very small compared to the entire object, representing at the same time its macro- and mesostructures. The main idea in this work is to use a visualization algorithm that is adequate to mesostructure but applied to the whole object. Tessellated models are converted into geometry textures, a geometric representation for surfaces based on height maps. In rendering time, the fine-scale details are reconstructed with LOD speed-up while preserving original quality [55].

6.1.23. Reverse Engineering for CAD Models

Keywords: *CAD models*, *Reverse engineering*, *model reconstruction*, *shape retrieval*, *surface recovery*, *topological algorithms*.

Participants: Rodrigo de Toledo, Bruno Lévy, Jean-Claude Paul.

CAD models are commonly represented by triangular meshes, which do not preserve original information about implicit surfaces used during design. The reverse-engineering algorithms presented in this paper focus on reconstructing implicit information, recovering original data. We propose two different approaches, a numerical one and an original topological approach. We explore specificities found in CAD meshes to achieve high effectiveness, reconstructing 90% of information from massive models (with millions of triangles) after few minutes of processing [20] [35].

6.1.24. Improved algebraic algorithm on point projection for Bézier curves

Keywords: *Algebraic pruning method*, *Continued fraction method*, *NURBS curve*, *Point projection*.

Participants: Xiao-Diao Chen, Yin Zhou, Zhenyu Shu, Hua Su, Jean-Claude Paul.

In this work, we presents an improved algebraic pruning method for point projection for Bézier curves. It first turns the point projection into a root finding problem, and provides a simple but easily overlooked method to avoid finding invalid roots which is obviously irrelative to the closest point. The continued fraction method and its expansion are utilized to strengthen its robustness. Since NURBS curves can be easily turned into Bézier form, the new method also works with NURBS curves. Examples are presented to illustrate the efficiency and robustness of the new method [27][6].

6.1.25. Automatic Least-Squares Projection of Points onto Point Clouds with Applications in Reverse Engineering

Keywords: *Point clouds*, *least-squares*, *projection*, *reverse engineering*.

Participants: Yu-Shen Liu, Jun-Hai Yong, Hui Zhang.

A novel method for projecting points onto a point cloud, possibly with noise, is presented based on the point directed projection (DP) algorithm proposed by Azariadis and Sapidis. Our method operates directly on the point cloud without any explicit or implicit surface reconstruction procedure. The presented method uses a simple, robust, and efficient algorithm: least-squares projection (LSP), which projects points onto the point cloud in a least-squares sense without any specification of the projection vector. The main contribution of this novel method is the automatic computation of the projection vector. Furthermore, we demonstrate the power and advantage of this approach through a number of application examples including thinning a point cloud, point normal estimation, projecting curves onto a point cloud and others [38] [37].

6.1.26. A quasi-Monte Carlo method for computing areas of point-sampled surfaces

Keywords: *Area*, *Intersection*, *Point-sampled surfaces*, *Quasi-Monte Carlo methods*.

Participants: Yu-Shen Liu, Jun-Hai Yong, Hui Zhang, Dong-Ming Yan, Jia-Guang Sun.

A novel and efficient quasi-Monte Carlo method for computing the area of a point-sampled surface with associated surface normal for each point is presented. Our method operates directly on the point cloud without any surface reconstruction procedure. Using the Cauchy-Crofton formula, the area of the point-sampled surface is calculated by counting the number of intersection points between the point cloud and a set of uniformly distributed lines generated with low-discrepancy sequences. Based on a clustering technique, we also propose an effective algorithm for computing the intersection points of a line with the point-sampled surface. By testing on a number of point-based models, experiments suggest that our method is more robust and more efficient than those conventional approaches based on surface reconstruction [39].

6.1.27. Computing Minimum Distance between Two Implicit Algebraic Surfaces

Keywords: *Minimum distance*, *canal surface*, *implicit algebraic surface*, *offset*, *parametric surface*.

Participants: Xiao-Diao Chen, Jun-Hai Yong, Jean-Claude Paul.

The minimum distance computation problem between two surfaces is very important in many applications such as robotics, CAD/CAM and computer graphics. Given two implicit algebraic surfaces, a new method based on the offset technique is presented to compute the minimum distance and a pair of points where the minimum distance occurs. The new method also works where there are an implicit algebraic surface and a parametric surface. Quadric surfaces, tori and canal surfaces are used to demonstrate our new method. When the two surfaces are a general quadric surface and a surface which is a cylinder, a cone or an elliptic paraboloid, the new method can produce two bivariate equations where the degrees are lower than those of any existing method [26].

6.1.28. A Rational Extension of Piegl's Method for Filling n-Sides Holes

Keywords: *N-sided hole*, *NURBS*, *coons surfaces*, *epsilon-G1 continuity*.

Participants: Jun-Hai Yong, Hui Zhang, Jean-Claude Paul.

N-sided hole filling plays an important role in vertex blending. To deal with the case that the corner is surrounded by rational surfaces (i.e. NURBS surfaces), an algorithm to fill n-sided holes with $\varepsilon - G^1$ continuous NURBS patches that interpolate the given boundary curves and approximate the given cross-boundary derivatives is presented based on Piegl's method. The NURBS surfaces joining along inner or boundary curves have normal vectors that do not deviate more than the user-specified angular tolerance ε. The boundaries as well as cross-boundary derivatives can all be NURBS curves. No restrictions are imposed on the number of boundary curves, and the cross-boundary derivatives can be specified independently [45].

6.1.29. Solid Reconstruction Using Recognition of Quadric Surfaces from Orthographic Views

Keywords: *Quadric surface*, *Solid reconstruction*, *feature recognition*, *orthographic projection*, *wire-frame*.

Participants: Jie-Hui Gong, Hui Zhang.

The reconstruction of 3D objects from 2D orthographic views is crucial for maintaining and further developing existing product designs. A B-rep oriented method for reconstructing curved objects from three orthographic views is presented by employing a hybrid wire-frame in place of an intermediate wire-frame. The Link-Relation Graph (LRG) is introduced as a multi-graph representation of orthographic views, and quadric surface features (QSFs) are defined by special basic patterns of LRG as well as aggregation rules. By hint-based pattern matching in the LRGs of three orthographic views in an order of priority, the corresponding QSFs are recognized, and the geometry and topology of quadric surfaces are recovered simultaneously. This method can handle objects with interacting quadric surfaces and avoids the combinatorial search for tracing all the quadric surfaces in an intermediate wire-frame by the existing methods. Several examples are provided [33].

6.1.30. An Example on Approximation by Fat Arcs and Fat Biarcs

Keywords: *Circular arc*, *biarc*, *fat arc*.

Participants: Jun-Hai Yong, Jean-Claude Paul.

Fat arcs form bounding boxes for planar curves. An example on approximation by fat arcs, provided by Qun and Rokne, is corrected. The third derivative of the given curve segment under the polar coordinate system is increasing only at the beginning of the curve segment, and then decreasing, rather than monotonically increasing for the whole curve segment. Some numerical data are corrected as well [48].

6.1.31. A C-Tree Decomposition Algorithm for 2D and 3D Geometric Constraint Solving

Keywords: *Geometric constraint solving*, *basic merge pattern*, *decomposition tree*, *general construction sequence*, *graph algorithm*, *parametric CAD*.

Participants: Xiao-Shan Gao, Qiang Lin, Gui-Fang Zhang.

We propose a method which can be used to decompose a 2D or 3D constraint problem into a C-tree. With this decomposition, a geometric constraint problem can be reduced into basic merge patterns, which are the smallest problems we need to solve in order to solve the original problem in certain sense. Based on the C-tree decomposition algorithm, we implemented a software package MMP/Geometer. Experimental results show that MMP/Geometer finds the smallest decomposition for all the testing examples efficiently [30].

6.1.32. Constrained Delaunay Triangulation Using Delaunay Visibility

Keywords: *Delaunay triangulation*, *delaunay visibility*.

Participants: Jun-Hai Yong, Hui Zhang, Jean-Claude Paul.

An algorithm for constructing constrained Delaunay triangulation (CDT) of a planar straight-line graph (PSLG) is presented. Although the uniform grid method can reduce the time cost of visibility determinations, the time needed to construct the CDT is still long. The algorithm proposed decreases the number of edges involved in the computation of visibility by replacing traditional visibility with Delaunay visibility. With Delaunay visibility introduced, all strongly Delaunay edges are excluded from the computation of visibility. Furthermore, a sufficient condition for DT (CDT whose triangles are all Delaunay) existence is presented to decrease the times of visibility determinations. The mesh generator is robust and exhibits a linear time complexity for randomly generated PSLGs [47].

6.1.33. Optimal Parameterizations of Bézier Surfaces

Keywords: *Parameterizations*.

Participants: Jun-Hai Yong, Hui Zhang, Jean-Claude Paul.

The presentation of Bézier surfaces affects the results of rendering and tessellating applications greatly. To achieve optimal parameterization, we present two reparameterization algorithms using linear Möbius transformations and quadratic transformations, respectively. The quadratic reparameterization algorithm can produce more satisfying results than the Möbius reparameterization algorithm with degree elevation cost. Examples are given to show the performance of our algorithms for rendering and tessellating applications [46].

6.2. Computer Graphics and Computer Animation

6.2.1. Perspective-aware texture analysis and synthesis

Keywords: *Perspectively featured texture*, *Scale map*, *Texture synthesis*.

Participants: Weiming Dong, Ning Zhou, Jean-Claude Paul.

This paper presents a novel texture synthesis scheme for anisotropic 2D textures based on perspective feature analysis and energy optimization. Given an example texture, the synthesis process starts with analyzing the texel (TEXture ELement) scale variations to obtain the perspective map (scale map). Feature mask and simple user-assisted scale extraction operations including slant and tilt angles assignment and scale value editing are applied. The scale map represents the global variations of the texel scales in the sample texture. Then, we extend 2D texture optimization techniques to synthesize these kinds of perspectively featured textures. The non-parametric texture optimization approach is integrated with histogram matching, which forces the global statics of the texel scale variations of the synthesized texture to match those of the example. We also demonstrate that our method is well-suited for image completion of a perspectively featured texture region in a digital photo [2] [28].

6.2.2. Robust tile-based texture synthesis using artificial immune system

Keywords: *Artificial immune system*, *Clonal selection*, *Sample patches selection*, *Texture synthesis*, *ω-tile*.

Participants: Weiming Dong, Ning Zhou, Jean-Claude Paul.

One significant problem in tile-based texture synthesis is the presence of conspicuous seams in the tiles. The reason is that sample patches employed as primary patterns of the tile set may not be well stitched if carelessly picked. In this paper, we introduce a robust approach that can stably generate an ω-tile set of high quality and pattern diversity. First, an extendable rule is introduced to increase the number of sample patches to vary the patterns in an ω-tile set. Second, in contrast to other concurrent techniques that randomly choose sample patches for tile construction, ours uses artificial immune system (AIS) to select the feasible patches from the input example. This operation ensures the quality of the whole tile set. Experimental results verify the high quality and efficiency of the proposed algorithm [13].

6.2.3. Simulating Human Visual Perception Result in Dark Illuminant Condition

Keywords: *Visual perception*, *bilateral filter*, *color vision model*, *mesopic vision*, *scotopic vision*, *visual acuity*.

Participants: Ning Zhou, Weiming Dong, Jiaxin Wang, Jean-Claude Paul.

In this paper, we present an image-based algorithm for simulating the visual adaptation of human visual system in different illuminant conditions, especially in nighttime condition. Human visual system exhibits different characteristics depending on the illuminant intensity, namely photopic vision in bright condition, scotopic vision in dark condition and mesopic vision between the former two. We set up a model to simulate multiple features of mesopic vision and scotopic vision, including chromaticity change, luminance change, and visual acuity loss. Our system takes a source image and a user-defined target illuminant map as input. Then we replace the daylight illuminant with target illuminant, and modify the chromaticity and luminance values of relighted scene assuming that the eye is adapted to the target illuminant. We introduce a bilateral filter to simulate the visual acuity loss. The parameters in our model have clear physical meanings, and can be obtained from experimental data to achieve realistic results [17].

6.2.4. Tile-Based Interactive Texture Design

Keywords: *Image composition*, *Interactive texture design*, *Texture synthesis*, *ω-tile*.

Participants: Weiming Dong, Ning Zhou, Jean-Claude Paul.

In this paper, we present a novel interactive texture design scheme based on the tile optimization and image composition. Given a small example texture, the design process starts with applying an optimized sample patches selection operation to the example texture to obtain a set of sample patches. Then a set of ω-tiles are constructed from these patches. Local changes to those tiles are further made by composing their local regions with the texture elements or objects interactively selected from other textures or normal images. Such select-compose pro- cess is iterated many times until the desired ω-tiles are obtained. Finally the tiles are tiled together to form a large texture. Our experimental results demonstrate that the proposed technique can be used for designing a large variety of versatile textures from a single small example texture, increasing or decreasing the decreasing the density of texture elements, as well as for synthesizing textures from multiple sources [12].

6.2.5. Texture Analysis and Classification With Linear Regression Model Based on Wavelet Transform

Keywords: *Linear regression*, *texture analysis*, *texture classification*, *wavelet transform*.

Participants: Zhi-Zhong Wang, Jun-Hai Yong.

The wavelet transform as an important multi-resolution analysis tool has already been commonly applied to texture analysis and classification. Nevertheless, it ignores the structural information while capturing the spectral information of the texture image at different scales. In this paper, we propose a texture analysis and classification approach with the linear regression model based on the wavelet transform. This method is motivated by the observation that there exists a distinctive correlation between the sample images, belonging to the same kind of texture, at different frequency regions obtained by 2-D wavelet packet transform. Experimentally, it was observed that this correlation varies from texture to texture. The linear regression model is employed to analyze this correlation and extract texture features that characterize the samples. Therefore, our method considers not only the frequency regions but also the correlation between these regions. In contrast, the pyramid-structured wavelet transform (PSWT) and the tree-structured wavelet transform (TSWT) do not consider the correlation between different frequency regions. Experiments show that our method significantly improves the texture classification rate in comparison with the multi-resolution methods, including PSWT, TSWT, the Gabor transform, and some recently proposed methods derived from these [15].

6.2.6. A Fast Sweeping Method for Computing Geodesics on Triangular Manifolds

Keywords: *Eikonal equation*, *Geodesics*, *fast marching methods*, *fast sweeping methods*, *triangular manifold*.

Participants: Song-Gang Xu, Yun-Xiang Zhang, Jun-Hai Yong.

A wide range of applications in computer intelligence and computer graphics require computing geodesics accurately and efficiently. The fast marching method (FMM) is widely used to solve this problem, of which the complexity is $O(N \log N)$, where N is the total number of nodes on the manifold. A fast sweeping method (FSM) is proposed and applied on arbitrary triangular manifolds, of which the complexity is reduced to $O(N)$. By traversing the undigraph, four orderings are built to produce two groups of interfering waves, which cover all directions of characteristics. The correctness of this method is proven by analyzing the coverage of characteristics. The convergence and error estimation are also presented [16].

6.2.7. Visual Simulation of Multiple Unmixable Fluids

Keywords: *Computational fluid dynamics*, *natural phenomena*, *physically based animation*.

Participants: Wen Zheng, Jun-Hai Yong, Jean-Claude Paul.

We present a novel grid-based method for simulating multiple unmixable fluids moving and interacting. Unlike previous methods that can only represent the interface between two fluids (usually between liquid and gas), this method can handle an arbitrary number of fluids through multiple independent level sets coupled with a constrain condition. To capture the fluid surface more accurately, we extend the particle level set method to a multi-fluid version. It shares the advantages of the particle level set method, and has the ability to track the interfaces of multiple fluids. To handle the dynamic behavior of different fluids existing together, we use a multiphase fluid formulation based on a smooth weight function [51].

6.2.8. Modeling and Visualization of Flower Color Patterns

Keywords: *Flower color*, *Image generation*, *Physically-based simulation*, *Visualization*.

Participants: Ning Zhou, Weiming Dong, Jiaxin Wang, Jean-Claude Paul.

Flowers are familiar in virtual scenes, however, the design of flower patterns is still mainly done by hand. To produce a number of flower color patterns required by a large scene can be very labor-consuming. In this work, we present a biologically-motivated algorithm for modeling and visualization of flower color patterns. It is able to produce various flower color patterns with little user interaction. In our system, pigmentation is simulated by a modified reaction-diffusion system, and the simulation function is controlled by a few experiential parameters. Thus it can be adjusted to produce various flower color patterns widely observed in the real world. Furthermore, our algorithm can be easily embedded into other advanced shading models to improve the quality of their rendering results. We present an image-based texture generation method as an example [53].

6.2.9. Optimized tile-based texture synthesis

Keywords: *genetic algorithm (GA)*, *sample patches selection*, *texture synthesis*, *ω-tile*.

Participants: Weiming Dong, Ning Zhou, Jean-Claude Paul.

One significant problem in tile-based texture synthesis is the presence of conspicuous seams in the tiles. The reason is that the sample patches employed as primary patterns of the tile set may not be well stitched if carelessly picked. In this work, we introduce an optimized approach that can stably generate an ω-tile set of high pattern diversity and high quality. Firstly, an extendable rule is introduced to increase the number of sample patches to vary the patterns in an ω-tile set. Secondly, in contrast to the other concurrent techniques that randomly choose sample patches for tile construction, our technique uses Genetic Algorithm to select the feasible patches from the input example. This operation insures the quality of the whole tile set. Experimental results verify the high quality and efficiency of the proposed algorithm [29].

6.2.10. Simulation of Bubbles

Keywords: *Fluid simulation*, *natural phenomenon*, *physically based animation*.

Participants: Wen Zheng, Jun-Hai Yong, Jean-Claude Paul.

We present a novel framework based on a continuous fluid simulator for general simulation of realistic bubbles, with which we can handle as many significant dynamic bubble effects as possible. To capture nature of the very thin liquid film of bubbles, we have developed a regional level set method allowing multi-manifold interface tracking. The regional level set method is based on the definitions of regional distance and its five operators, which makes it very easy to implement. We can reconstruct an implicit surface of liquid film with arbitrary thickness from the representation of regional level set functions. To overcome the numerical instability caused by surface tension, we exploit a new semi-implicit surface tension model which is unconditionally stable and makes the simulation of surface tension dominated phenomena much more efficient. An approximated film thickness evolution model is proposed to control the bubble¡¯s lifecycle. All these new techniques combine into a general framework that can produce various realistic dynamic effects of bubbles [50].

7. Contracts and Grants with Industry

7.1. Mesh-NURBS Intersection with CHIDI China

Participants: Jean-Claude Paul, Jun-Hai Yong, Nabil Anwer.

In the modern CAD based design activity, it is important to provide tools that enable the creation of complex objects from simple features. Boolean operations are the main operations that could be used at this level. In our case, we should perform Boolean operations between Nurbs and meshes (Union, Intersection and difference are the main operations).

In a general way, a Boolean operation proceeds in two stages:

- Calculation of intersection curves between surfaces of the two primitives implied in the operation: intersection points are then computed and then connected to approach the intersection curve;
- Conservation of the parts of the primitives necessary to the construction of the surface of the resulting object according to the Boolean operation considered and the nature of the surface (mesh or nurbs).

Currently, there is no feasible well-designed Nurbs-Mesh Boolean operation algorithm in both research and industrial field [42]. As a first step, we have proposed an algorithm for mesh-mesh Boolean operations.

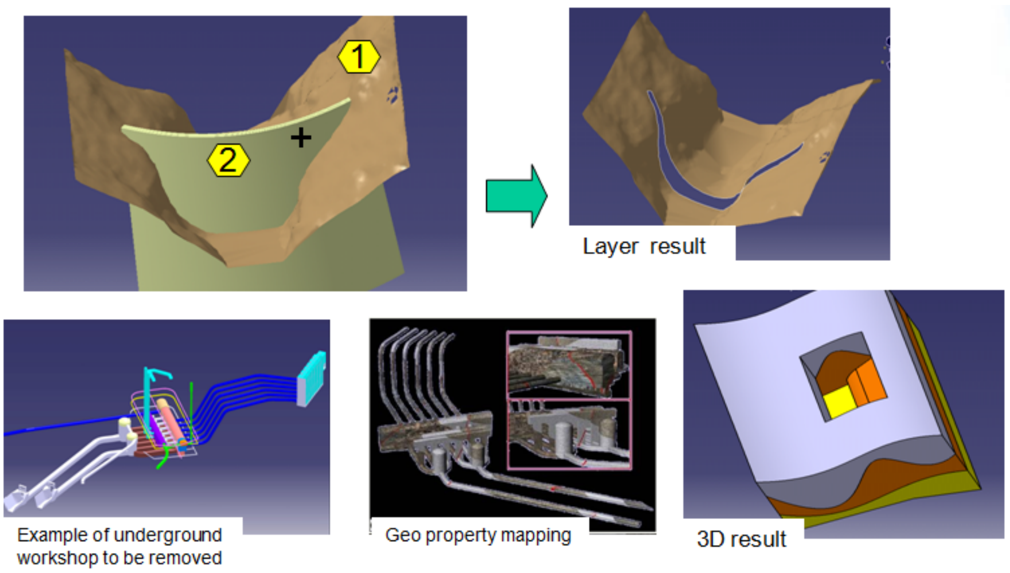

Figure 2. Plant interaction: Impact Operation (from SimuTech)

8. Other Grants and Activities

8.1. Grants and Awards

Jun-Hai Yong Excellent Supervisor Award of Student Research Training (SRT) Program at Tsinghua University in 2007.

Excellent Teaching Award for Young Teachers by Tsinghua University in 2007.

8.2. European Projects

The Institute of CAD (Tsinghua) is a Chinese Member of the European Project **aim@shape**.

8.3. International Initiatives

The *ACM Symposium on Solid and Physical Modeling* (ACM/IEEE 2007) has been chaired in Beijing by Pr. Jia-Guang Sun (Tsinghua University), director of School of Information Science and Technology at Tsinghua. Dr. Bruno Lévy (INRIA) co-chaired the committee papers.

The *IEEE International Conference of Shape Modeling* in 2009 will be co-chaired at Beijing by Pr. Jia-Guang Sun (Tsinghua University) and Pr. Jean-Claude Paul (INRIA).

9. Dissemination

9.1. Teaching

- Pr. Jun-Hai Yong, Pr. Jean-Claude Paul, Dr. Hui Zhang and Dr. Bin Wang give courses in the School of Software and in the Department of Computer Science at Tsinghua University.
- Dr. Hui Zhang is the Vice Dean of the School of Software at Tsinghua University since July 2006.

9.2. Invited Talks

Pr. Jean-Claude Paul gave lectures at Wuhan University, Hunan University, Guilin University, Xiamen University and Zhejiang University.

9.3. Visiting Scientists

Every year, Pr. Jean-Claude Paul and Pr. Jun-Hai Yong organize lectures and courses of INRIA researchers at Tsinghua University.

In 2007, they organize the Computational Geometry and Computer Graphics program with Frédo Durand (MIT), Francois Sillion (INRIA), Bruno Lèvy (INRIA), Jean-Daniel Boissonat (INRIA) and Pierre Aliez (INRIA).

In 2008, they organize the Formal Methods program with Pierre-Louis Curien (CNRS), Jean-Pierre Jouannaud (Ecole Polytechnique), Frederic Blanqui (INRIA), Yves Bertot (INRIA), Helene Kichner (INRIA), Claude Kichner (INRIA) and Stephan Merz (INRIA).

9.4. Program Committees

Pr. Jun-Hai Yong and Pr. Jean-Claude Paul are Programm Committee Members and Reviewers in several International Journals and Conferences.

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