IP0

Pierre Bézier Award Lecture: Bézier, B-splines and Beyond

In an interleaved presentation drawing on many years of personal interactions with him, the recipients will begin by presenting some historical remarks concerning less known but important lessons learned from Pierre Bézier on how he achieved enormous impact. These certainly increased our appreciation and understanding for viewing mathematical contributions to CAD/CAM and modeling research in a larger context. This will help to highlight how his insight and work contributed inspiration for much of our subsequent work on B-spline methods applied to CAD/CAM, geometric modeling and computer graphics. By taking a long perspective in time on major advances in the field, we will try to assess where we are and indentify issues that call for redoubled efforts in the future. This analysis exposes that, in a somewhat ironic turn of events, we are now embarking on a recurring cycle of historical themes, a kind of wheel of reincarnation, albeit in a vastly more sophisticated and complex setting.

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IP1

The Science of Computational Modeling

Computational modeling has many facets. Included in the list would be the mathematics of discretized approximations to partial differential equations, the computer science of programming parallel codes to effectively and accurately solve the resulting system of equations, the fundamental physics being modeled, etc. However, there is one aspect of the computational modeling process where the science employed is too often overlooked or underplayed. This aspect is the science needed to generate the models themselves. The generation of models continues to be a fundamental limiting problem in the overall mod/sim environment. However, solving this modeling bottleneck is often seen as more "D' than "R' in the R&D balance. In spite of this narrow perspective, the fundamental science questions needing addressed are diverse, particularly difficult, and carry a tremendous payoff potential if solved well. In fact, the research challenges dominate progress. This talk will focus on some of these "modeling science' issues, identifying the obstacles, some of the approaches taken to date to solve them, and the remaining potential as work continues.

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IP2

Practical Issues of Geometry/Physical Modeling in a Movie Production World

In this talk, I'll discuss assorted lessons learned and experience gained in dealing with the geometric complexities and modeling issues that arise in simulating the physics of cloth, hair, and water in a movie production environment. The talk content will discuss a broad range of geometric and modeling topics and issues, with an emphasis on what happens when theoretical results (and not so theoretical implementors) have their feet held to the fire in the realities of a production driven environment. The talk will attempt to eschew any complicated mathematical equations/algorithms and focus rather on video examples to get the point across.

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IP3

Multiresolution Modeling with Constraints

Multiresolution analysis has received considerable attention in recent years by researchers in the fields of computer graphics, geometric modeling and visualization. Its attraction is its inherent ability for efficiently representing curves and surfaces at multiple levels-of-detail (LOD). So it is a powerful tool for several applications, including compression, LOD display, progressive transmission and LOD editing. In this talk, various multiresolution representations (not only wavelet based) for curves, surfaces and triangular meshes are given. We then emphasize on the integration of constraints in the multiresolution model. This leads to intuitive and efficient tools for manipulating multiresolution curves and surfaces.

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IP4

Isogeometric Analysis: Promises, Experiences and Challenges

There exists a "great divide" between the CAD (Computer Aided Design) approaches for modeling complex geometries and the numerical simulation methods, in particular the FEM (Finite Element Method), which is only able to approximate free-form shapes. This divide constitutes a severe bottleneck in the development process since the CAD model needs to be converted to a computational mesh whose generation typically demands a great effort and which is not an appropriate basis for design changes and life cycle management. Simulation methods that exactly represent engineering shapes and that vastly simplify the mesh generation by eliminating the necessity to communicate with the CAD description hold great promise. Though the idea of bridging the gap between the CAD and the FEM approaches can be traced back to the early days of finite element simulation, it has only recently gained significant momentum by the introduction of the method of isogeometric analysis by T.J.R. Hughes et al. (2005). This talk reports on our experiences with this approach and describes some of the challenging problems associated with it.

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IP5

Gradient-Based Algorithms for Shape Deformation

Shape deformation refers to the continuous change of one geometric shape to another. Shape deformation techniques are useful in a variety of applications in computer modeling and animation. These techniques are widely used by artists to sculpt stylized body shapes and deformations for 3D characters. Most traditional techniques, such as free-form deformation (FFD), multi-resolution methods, manipulate surface positions explicitly. The speaker will review a few fascinating properties of recently developed gradient-based algorithms, which encodes surface details differentially, i.e., as local differences or derivatives. These algorithms preserve surface details and produce visually pleasing deformation results by distributing errors globally through least-squares minimization. The talk will explore the origin of gradient-based algorithms and present latest advances in this new and continuously evolving area.

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IP6

Structure Discovery in 3D Geometry

Digital models of physical shapes are becoming ubiquitous in our economy and life. Such models are sometimes designed ab initio using CAD tools, but more and more often they are based on existing real objects whose shape is acquired using various 3D scanning technologies. In most instances, the original scanner data is just a set of points sampled from the surface of the object. We are interested in tools for understanding the local and global structure of such scanned geometry for a variety of tasks, including model completion, reverse engineering, shape comparison and retrieval, shape editing, inclusion in virtual worlds and simulations, etc. This talk will present a number of point-based techniques for discovering global structure in such data sets, such as topology extraction, approximate reconstruction with guarantees, or symmetry/repeated pattern detection. The irregular and dynamic sampling in the point data creates new challenges and leads to methods with a distinctly more combinatorial and topological character.

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CP0

A Symbolic-Numerical Envelope Algorithm Using Quadratic MOS Patches

In this paper, we describe an algorithm for generating an exact rational envelope of a two-parameter family of spheres given by a quadratic patch in $\mathbf{R}^{3,1}$, which is considered as a medial surface transform (MST) of a spatial domain. Recently, it has been proved that quadratic triangular Bézier patches in $\mathbf{R}^{3,1}$ belong to the class of MOS surfaces (i.e., surfaces providing rational envelopes of the associated two-parameter family of spheres). We give a detailed description of the symbolic and numerical steps of the envelope algorithm and study the error involved in the numerical part. The presented method is then demonstrated on several examples. Moreover, since quadratic MOS patches are capable of producing C^1 approximations of MSTs, this algorithm offers a good basis for consequent methods, e.g. computing rational approximations of envelopes associated to general (free-form) MSTs and inner offsets trimming.

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CP0

Repairing and Meshing Imperfect Shapes with Delaunay Refinement

As a direct consequence of software quirks, designer errors, and representation flaws, often three-dimensional shapes are stored in formats that introduce inconsistencies such as small gaps and overlaps between surface patches. We present a new algorithm that simultaneously repairs imperfect geometry and topology while generating Delaunay meshes of these shapes. At the core of this approach is a meshing algorithm for input shapes that are piecewise smooth complexes (PSCs), a collection of smooth surface patches meeting at curves non-smoothly or in non-manifold configurations. Guided by a user tolerance parameter, we automatically merge nearby components while building a Delaunay mesh that has many of these errors fixed. Experimental evidence is provided to show the results of our algorithm on common computer-aided design (CAD) formats. Our algorithm may also be used to simplify shapes by removing small features which would require an excessive number of elements to preserve them in the output mesh.

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CP0

A Dynamic Data Structure for Flexible Molecular Maintenance and Informatics

We present the "Dynamic Packing Grid" (DPG) data structure along with details of our implementation and numerous performance charts, for maintaining and manipulating flexible molecular models and assemblies. DPG can efficiently maintain the molecular surface (e.g., van der Waals surface and the solvent contact surface) under insertion/deletion/movement (also called updates) of atoms or groups of atoms. DPG also permits the fast estimation of important molecular properties (e.g., surface area, volume, polarization energy, etc.) that are needed for computing binding affinities in drug design or in molecular dynamics calculations. DPG can additionally be utilized in efficiently maintaining multiple "rigid" domains of dynamic flexible molecules. In DPG, each insertion/deletion/movement update takes only $O(1)$ time and hence is extremely fast. DPG's queries include the reporting of all atoms within $O(r_{\max})$ distance from any given atom or a point in 3-space in $O(\log\log w)(= O(1))$ time w.h.p., where $r_{\max}$ is the radius of the largest ball in the union. An additional DPG query in $O(1)$ time is whether a given atom is exposed or buried under the surface within the same time bound. Hence one can use DPG to generate the entire molecular surface in $O(m)$ worst-case time, where m is the number of atoms on the molecular surface. The data structure uses space linear in the number of atoms of the molecule.

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CP0

A Sketching Interface for Feature Curve Recovery of Free-Form Surfaces

In this paper, we present a semi-automatic approach to efficiently and robustly recover the characteristic feature curves of a given free-form surface. The technique supports a sketch-based interface where the user just has to roughly sketch the location of a feature by drawing a stroke directly on the input mesh. The system then snaps this initial curve to the correct position based on a graph-cut optimization scheme that takes various surface properties into account. Additional position constraints can be placed and modified manually which allows for an interactive feature curve editing functionality. We demonstrate the usefulness of our technique by applying it to a practical problem scenario in reverse engineering. Here, we consider the problem of generating a statistical (PCA) shape model for car bodies. The crucial step is to establish proper feature correspondences between a large number of input models. Due to the significant shape variation, fully automatic techniques are doomed to failure. With our simple and effective feature curve recovery tool, we can quickly sketch a set of characteristic features on each input model which establishes the correspondence to a pre-defined template mesh and thus allows us to generate the shape model. Finally, we can use the feature curves and the shape model to implement an intuitive modeling metaphor to explore the shape space spanned by the input models.

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CP0

Discrete Physics Using Metrized Chains

Over the last fifty years, there have been numerous efforts to develop comprehensive discrete formulations of geometry and physics from first principles: from Whitney's geometric integration theory to Harrison's theory of chainlets, including Regge calculus in general relativity, Tonti's work on the mathematical structure of physical theories and their discrete formulation, plus multifarious researches into so-called mimetic discretization methods, discrete exterior calculus, and discrete differential geometry. All these approaches strive to tell apart the different mathematical structures—topological, differentiable, metrical—underpinning a physical theory, in order to make the relationships between them more transparent. While each component is reasonably well understood, computationally effective connections between them are not yet well established, leading to difficulties in combining and progressively refining geometric models and physics-based simulations. This paper proposes such a connection by introducing the concept of metrized chains, meant to establish a discrete metric structure on top of a discrete measure-theoretic structure embodied in the underlying notion of measured (real-valued) chains. These, in turn, are defined on a cell complex, a finite approximation to a manifold which abstracts only its topological properties. The algebraic-topological approach to circuit design and network analysis first proposed by Branin was later extensively applied by Tonti to the study of the mathematical structure of physical theories. (Co-)chains subsequently entered the field of physical modeling and were related to commonly-used discretization methods such as finite elements, finite differences, and finite volumes. Our modus operandi is characterized by the pivotal role we accord to the construction of a physically based inner product between chains. This leads us to criticize the emphasis placed on the choice of an appropriate dual mesh: in our opinion, the "good" dual mesh is but a red herring, in general.

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CP0

Exact Delaunay Graph of Smooth Convex Pseudo-Circles: General Predicates, and Implementation for Ellipses

We examine the problem of computing exactly the Delaunay graph (and the dual Voronoi diagram) of a set of, possibly intersecting, smooth convex pseudo-circles in the Euclidean plane, given in parametric form. Pseudo-circles are (convex) sites, every pair of which has at most two intersecting points. The Delaunay graph is constructed incrementally. Our first contribution is to propose robust end efficient algorithms for all required predicates, thus generalizing our earlier algorithms for ellipses, and we analyze their algebraic complexity, under the exact computation paradigm. Second, we focus on InCircle, which is the hardest predicate, and express it by a simple sparse 5x5 polynomial system, which allows for an efficient implementation by means of successive Sylvester resultants and a new factorization lemma. The third contribution is our CGAL-based C++ software for the case of ellipses, which is the first exact implementation for the problem. Our code spends about 98 sec to construct the Delaunay graph of 128 non-intersecting ellipses, when few degeneracies occur. It is faster than the CGAL segment Delaunay graph, when ellipses are approximated by k-gons for k¿15.

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CP0

Nonlinear Systems Solver in Floating-Point Arithmetic Using LP Reduction

This paper presents a new solver for systems of nonlinear equations. Such systems occur in Geometric Constraint Solving, e.g., when dimensioning parts in CAD-CAM, or when computing the topology of sets defined by nonlinear inequalities. The paper does not consider the problem of decomposing the system and assembling solutions of subsystems. It focuses on the numerical resolution of well-constrained systems. Instead of computing an exponential number of coefficients in the tensorial Bernstein basis, we resort to linear programming for computing range bounds of system equations or domain reductions of system variables. Linear programming is performed on a so called Bernstein polytope: though, it has an exponential number of vertices (each vertex corresponds to a Bernstein polynomial in the tensorial Bernstein basis), its number of hyperplanes is polynomial: $O(n^2)$ for a system in n unknowns and equations, and total degree at most two. An advantage of our solver is that it can be extended to non-algebraic equations. In this paper, we present the Bernstein and LP polytope construction, and how to cope with floating point inaccuracy so that a standard LP code can be used. The solver has been implemented with a primal-dual simplex LP code, and some implementation variants have been analyzed. Furthermore, we show geometric-constraint-solving applications, as well as numerical intersection and distance computation examples.

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CP0

SOT: Compact Representation for Tetrahedral Meshes

The Corner Table (CT) promoted by Rossignac et al. provides a simple and efficient representation of triangle meshes, storing 6 integer references per triangle (3 vertex references in the V table and 3 references to opposite corners in the O table that accelerate access to adjacent triangles). The Compact Half Face (CHF) proposed by Lage et al. extends CT to tetrahedral meshes, storing 8 references per tetrahedron (4 in the V table and 4 in the O table). We call it the Vertex Opposite Table (VOT) and propose a sorted variation, SVOT, which does not require any additional storage and yet provides, for each vertex, a reference to an incident corner from which an incident tetrahedron may be recovered and the star of the vertex may be traversed at a constant cost per visited element. We use a set of powerful wedge-based operators for querying and traversing the mesh. Finally, inspired by tetrahedral mesh encoding techniques used by Weiler et al. and by Szymczak and Rossignac, we propose our Sorted O Table (SOT) variation, which eliminates the V table completely and hence reduces storage requirements by 50% to only 4 references and 9 bits per tetrahedron, while preserving the vertex-to-incident-corner references and supporting our wedge operators with a linear average cost.

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CP0

Particle-Based Forecast Mechanism for Continuous Collision Detection in Deformable Environments

Collision detection in geometrically complex scenes is crucial in physical simulations and real time applications. Works based on spatial hierarchical structures have been proposed for years. If correct performances are obtained for static scenes, these approaches show some limitations when the complexity of the scene increases and particularly in case of deformable meshes. The main drawback is the time needed to update the spatial structures - often trees - when global deformations or topological changes occur in the scene. We propose a method to detect collisions in complex and deformable environments with constant time amortized complexity for small displacements. Our method is based on a convex decomposition of the environment coupled with a forecast mechanism exploiting temporal coherence. We use the topological adjacencies and incidence relationships to reduce the number of geometrical tests. Deformations of the scenes are handled with no cost as far as no topological changes occur. Topological transformations, like cuts and sewings, are handled locally, exploiting the spatial coherence and do not imply global updates. We illustrate our method in two experimental frameworks: a particles flow simulation and a meshless animation system both lying in a deformable mesh. We compare our work with classical optimization based on bounding volumes hierarchies to validate its efficiency on large scenes.

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CP0

Accelerating Geometric Queries Using the GPU

We present practical algorithms for accelerating geometric queries on models made of NURBS surfaces using programmable Graphics Processing Units (GPUs). We provide a generalized framework for using GPUs as coprocessors in accelerating CAD operations. By attaching the data corresponding to surface-normals to a surface bounding-box structure, we can calculate view-dependent geometric features such as silhouette curves in real time. We make use of additional surface data linked to surface bounding-box hierarchies on the GPU to answer queries such as finding the closest point on a curved NURBS surface given any point in space and evaluating the clearance between two solid models constructed using multiple NURBS surfaces. We simultaneously output the parameter values corresponding to the solution of these queries along with the model space values. Though our algorithms make use of the programmable fragment processor, the accuracy is based on the model space precision, unlike earlier graphics algorithms that were based only on image space precision. In addition, we provide theoretical bounds for both the computed minimum distance values as well as the location of the closest point. Our algorithms are at least an order of magnitude faster than the commercial solid modeling kernel ACIS.

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CP0

Robust Voronoi-Based Curvature and Feature Estimation

We present practical algorithms for accelerating geometric queries on models made of NURBS surfaces using programmable Graphics Processing Units (GPUs). We provide a generalized framework for using GPUs as co-processors in accelerating CAD operations. By attaching the data corresponding to surface-normals to a surface bounding-box structure, we can calculate view-dependent geometric features such as silhouette curves in real time. We make use of additional surface data linked to surface bounding-box hierarchies on the GPU to answer queries such as finding the closest point on a curved NURBS surface given any point in space and evaluating the clearance between two solid models constructed using multiple NURBS surfaces. We simultaneously output the parameter values corresponding to the solution of these queries along with the model space values. Though our algorithms make use of the programmable fragment processor, the accuracy is based on the model space precision, unlike earlier graphics algorithms that were based only on image space precision. In addition, we provide theoretical bounds for both the computed minimum distance values as well as the location of the closest point. Our algorithms are at least an order of magnitude faster than the commercial solid modeling kernel ACIS.

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CP0

Constraint-Based Model Synthesis

We present a method for procedurally modeling general complex 3D shapes. Our approach is targeted towards applications in digital entertainment and gaming and can automatically generate complex models of buildings, man-made structures, or urban datasets in a few minutes based on user-defined inputs. The algorithm attempts to generate results that resemble a user-defined input model and that satisfy various dimensional, geometric, and algebraic constraints. These constraints are used to capture the intent of the user and generate shapes that look more natural. We also describe efficient techniques to handle complex shapes and demonstrate their performance on many different types of models.

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Tracing Ridges on B-Spline Surfaces

Ridges are characteristic curves of a surface that mark salient intrinsic features of its shape and are therefore valuable for shape matching, surface quality control, visualization and various other applications. Ridges are loci of points on a surface where either of the principal curvatures attain a critical value in its respective principal direction. These curves have complex behavior near umbilics on a surface, and may also pass through certain turning points causing added complexity for ridge computation. We present a new algorithm for numerically tracing ridges on B-Spline surfaces that also accurately captures ridge behavior at umbilics and ridge turning points. The algorithm traverses ridge segments by detecting ridge points while advancing and sliding in principal directions on a surface in a novel manner, thereby computing connected curves of ridge points. The output of the algorithm is a set of curve segments, some or all of which, may be selected for other applications such as those mentioned above. The results of our technique are validated by comparison with results from previous research and with a brute-force domain sampling technique.

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CP0

Configuration Products in Solid Modeling

The six-dimensional space SE(3) is traditionally associated with the space of configurations of a rigid solid (a subset of Euclidean three-dimensional space E^3). But a solid can be also considered to be a set of configurations, and therefore a subset of SE(3). This observation removes the artificial distinction between shapes and their configurations, and allows formulation and solution of a large class of problems in mechanical design and manufacturing. In particular, the configuration product of two subsets of configuration space is the set of all configurations obtained when one of the sets is transformed by all configurations of the other. The usual definitions of various sweeps, Minkowski sum, and other motion related operations are then realized as projections of the configuration product into E^3. Similarly, the dual operation of configuration quotient subsumes the more common operations of unsweep and Minkowski difference. We identify the formal properties of these operations that are instrumental in formulating and solving both direct and inverse problems in computer aided design and manufacturing. Finally, we show that all required computations may be implemented using a fast parallel sampling method on a GPU.

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CP0

A Framework for Preservable Geometry-Centric Artifacts

Digital preservation is the mitigation of the deleterious effects of technology obsolescence, media degradation, and fading human memory. For engineering, design, manufacturing, and physics-based simulation data this requires formats that are semantically accessible for 30-to-50 year lifespans. One of the fundamental challenges is the development of digital geometry-centric engineering representations that are self describing and assured to be interpretable over the long lifespans required by archival applications. This paper introduces the challenge of long-term preservation of digital geometric models. We describe a digital preservation case study for an engineering model which required, for just a single part, over 3.5 GB of data, including 39 file formats and over 750 distinct model and shape files. Based on lessons learned in this case study, we present a framework for enhancing the preservation of geometry-centric engineering knowledge. This framework is currently being used on a number of projects in engineering education.

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CP0

Robust Mesh Reconstruction from Unoriented Noisy Points

We present a robust method to generate mesh surfaces from unoriented noisy points in this paper. The whole procedure consists of three steps. Firstly, the normal vectors at points are evaluated by a highly robust estimator which can fit surface corresponding to less than half of the data points and fit data with multi-structures. This benefits us with the ability to well reconstruct the normal vectors around sharp edges and corners. Meanwhile, clean point cloud equipped with piecewise normal is obtained by projecting points according to the robust fitting. Secondly, an error-minimized subsampling is applied to generate a well-sampled point cloud. Thirdly, a combinatorial approach is employed to reconstruct a triangular mesh connecting the down-sampled points, and a polygonal mesh which preserves sharp features is constructed by the dual-graph of triangular mesh. Parallelization method of the algorithm on a consumer PC using the architecture of GPU is also given.

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CP0

A Geometric Criterion for Smooth Interpolation of Curve Networks

A key problem when interpolating a network of curves occurs at vertices: an algebraic condition called the vertex enclosure constraint must hold wherever an even number of curves meet. This paper recasts the constraint in terms of the local geometry of the curve network. This allows formulating a new geometric constraint, related to Eulers Theorem on local curvature, that implies the vertex enclosure constraint and is equivalent to it where four curve segments meet without forming an X.

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Mesh Cutting During Real-Time Physical Simulation

The ability to cut through meshes in real-time is an essential ingredient in a number of practical interactive simulations. Surgical simulation, cloth design, clay sculpting and many other related VR applications require the ability to introduce arbitrary discontinuities through models to separate, reposition and reshape various pieces of the model as needed for the target application. In addition, in order to provide the necessary realism for these applications, model deformations must be computed from an underlying physically-based model–most commonly a continuum-based finite element model. In this work, we present a method for representing and computing, at interactive rates, the deformations of a mesh whose topology is being dynamically modified with multiple virtual tools. The method relies on introducing controlled discontinuities in the basis functions used to represent the geometry of deformation, and on fast incremental methods for updating global model deformations. The method can also generate the forces needed for force rendering in a haptic environment. The method is shown to scale well with problem size (linearly in the number of nonzeros of the Cholesky factor) allowing realistic interaction with fairly large models. The work presented can be viewed as a more general alternative to discontinuous free form deformations, methods that pre-determine and/or limit allowable interactions with the model, and methods that use simplified/pseudo-physics to compute model deformations.

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CP0

Treedecomposition of Geometric Constraint Graphs Based on Computing Graph Circuits

The graph-based geometric constraint solving technique works in two steps. First the geometric problem is translated into a graph whose vertices represent the set of geometric elements and whose edges are the constraints. Then the constraint problem is solved by decomposing the graph into a collection of subgraphs each representing a standard problem which is solved by a dedicated equational solver. In this work we report on an algorithm to decompose biconnected tree-decomposable graphs representing either under- or wellconstrained 2D geometric constraint problems. The algorithm recursively first computes a set of fundamental circuits in the graph then splits the graph into a set of subgraphs each sharing exactly three vertices with the fundamental circuit. Practical experiments show that the reported algorithm clearly outperforms the treedecomposition approach based on identifying subgraphs by applying specific decomposition rules.

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CP0

B-Morphs Between B-Compatible Curves in the Plane

We define b-compatibility for planar curves and propose three ball morphing techniques (b-morphs) between pairs of b- compatible curves. B-morphs use the automatic ball-map correspondence, proposed by Chazal et al., from which they derive vertex tra jectories (Linear, Circular, Parabolic). All are symmetric, meeting both curves with the same angle, which is a right angle for the Circular and Parabolic. We provide simple constructions for these b-morphs using the maximal disks in the finite region bounded by the two curves. We compare the b-morphs to each other and to other simple morphs (Linear Interpolation (LI), Closest Projection(CP), Curvature Interpolation (CI), Laplace Blending (LB), Heat Propagation (HP)) using seven measures of quality deficiency (travel distance, distortion, stretch, local acceleration, surface area, average curvature, maximal curvature). We conclude that the ratios of these measures depends heavily on the test case, especially for LI, CI, and LB, which compute correspondence from a uniform geodesic parameterization. Nevertheless, we found that the Linear b- morph has consistently the shortest travel distance and that the Circular b-morph has the least amount of distortion.

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CP0

Testing An Axis of Rotation for 3D Workpiece Draining

Given a triangular mesh defining the geometry of a 3D workpiece filled with water, we propose an algorithm to test whether, for an arbitrary given axis, the workpiece will be completely drained under gravity when rotated around the axis. Observing that all water traps contain a concave vertex, we solve our problem by constructing and analyzing a directed draining graph whose nodes correspond to concave vertices of the geometry and whose edges are set according to the transition of trapped water when we rotate the workpiece around the given axis. Our algorithm to check whether or not a given rotation axis drains the workpiece outputs a result in about a second for models with more than 100,000 triangles.

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CP0

Log-Aesthetic Space Curve Segments

For designing aesthetic surfaces, such as the car bodies, it is very important to use aesthetic curves as characteristic lines. In such curves, the curvature should be monotonically varying, since it dominates the distortion of reflected images on curved surfaces. In this paper, we present an interactive control method of log-aesthetic space curves. We define log-aesthetic space curves to be curves whose logarithmic curvature and torsion graphs are both linear. The linearity of these graphs constrains that the curvature and torsion are monotonically varying. We clarify the characteristics of log-aesthetic space curves and identify their family. Moreover, we present a novel method for drawing a log-aesthetic space curve segment by specifying two endpoints, their tangents, the slopes, α and β, of straight lines of the logarithmic curvature and torsion graphs, and the torsion parameter Ω. Our implementation shows that log-aesthetic curve segments can be controlled fully interactively.

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CP0

On the Parameterization of Catmull-Rom Curves

The behavior of Catmull-Rom curves heavily depends on the choice of parameter values at the control points. We analyze a class of parameterizations ranging from uniform to chordal parameterization and show that, within this class, curves with centripetal parameterization contain properties that no other curves in this family possess. Researchers have previously indicated that centripetal parameterization produces visually favorable curves compared to uniform and chordal parameterizations. However, the mathematical reasons behind this behavior have been ambiguous. In this paper we prove that, for cubic Catmull-Rom curves, centripetal parameterization is the only parameterization in this family that guarantees that the curves do not form cusps or self-intersections within curve segments. Furthermore, we provide a formulation that bounds the distance of the curve to the control polygon and explain how globally intersectionfree Catmull-Rom curves can be generated using these properties.

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CP0

Generalized Koebe's Method for Conformal Mapping Multiply Connected Domains

Surface parameterization refers to the process of mapping the surface to canonical planar domains, which plays crucial roles in texture mapping and shape analysis purposes. Most existing techniques focus on simply connected surfaces. It is a challenging problem for multiply connected genus zero surfaces. This work generalizes conventional Koebe's method for multiply connected planar domains. According to Koebe's uniformization theory, all genus zero multiply connected surfaces can be mapped to a planar disk with multiply circular holes. Furthermore, this kind of mappings are angle preserving and differ by Möbius transformations. We introduce a practical algorithm to explicitly construct such a *circular conformal mapping*. Our algorithm pipeline is as follows: suppose the input surface has boundaries, first we choose boundaries, and fill the other boundaries to get a topological annulus; then we apply discrete Yamabe flow method to conformally map the topological annulus to a planar annulus; then we remove the filled patches to get a planar multiply connected domain. We repeat this step for the planar domain iteratively. The two chosen boundaries differ from step to step. The iterative construction leads to the desired conformal mapping, such that all the boundaries are mapped to circles. In theory, this method converges quadratically faster than conventional Koebe's method. We give theoretic proof and estimation for the converging rate. In practice, it is much more robust and efficient than conventional non-linear methods based on curvature flow. Experimental results demonstrate the robustness and efficiency of the method.

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CP1

Triangular Bézier Developable Patches

During the last decade there have many advances in construction of developable surfaces within NURBS formalism. Much of this efforts have been devoted to solving the nonlinear null gaussian curvature condition for Bézier, rational and spline tensor product developable patches. In this talk we would like to address the issue of Bézier triangular patches. It will be shown that much of our knowledge of developable tensor product patches can be extended to triangular patches, though there are specific problems. A large class of developable triangular patches will be derived in terms of two functions. This construction will be related to relevant CAGD algorithms, such as degree elevation and subdivision.

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CP1

New Polynomial Basis Functions over Hierarchical T-Meshes

We suggest some new polynomial basis functions over hierarchical T-meshes for geometric modeling. While the well-known T-splines are usually rational, our proposed bases are just polynomial because they are generated by direct manipulation of the known B-spline basis functions. Using these proposed bases, our method can compute the local refinement with T-junction. Our bases have the same important properties as of B-splines such as non-negativity, local support and partition of unity. We illustrate with an example for 'z-map' model.

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CP1

On the Injectivity of Generalized Barycentric Mappings

The injectivity of barycentric mappings (mean value, Wachspress) is important for curve deformation: we would like a guarantee that when we deform a curve we do not introduce any new self-intersections. In our presentation we will focus on a generalization of Wachspress mappings, the so called Warren-Wachspress mappings [Warren, J., Schaefer, S., Hirani, A., Desbrun, M., Barycentric coordinates for convex sets]. These mappings are defined over a smooth convex domain and can be used to map such a domain into another convex domain. As the main contribution we will discuss the injectivity of these mappings.

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CP1

Computing Spline Properties from the Control Polygon

A fundamental property of splines expressed in terms of B-splines is how the control polygon provides an adaptive (via subdivision), discrete version of the underlying smooth shape. In this talk we will consider a number of recent algorithms that exploit this relationship for computing (amongst others): All zeros of a spline function, intersections of two spline curves, the Chebyshev Spline (a generalisation of the Chebyshev Polynomial) and others.

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CP1

Practical C^1 Reparametrization of Piecewise Rational Bézier Curves

Piecewise rational Bézier curves with G^1-continuity in the projective space provide a useful tool for shape blending applications with complex boundary conditions where visual continuity is required. We present an efficient method to construct such curves given an initial sequence of rational segments G^1-continuous in the affine space. Combination of degree elevation and linear rational reparametrization can be used to transform the curve in the projective space in order to optimize the parametrization with respect to the parametric speed.

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CP2

A Class of Generalized Midpoint Subdivision Schemes

Connecting the midpoints of adjacent faces or of adjacent face edges of a quadrilateral mesh with irregular vertices and irregular faces, we obtain two well-known smoothing operators used in midpoint and midedge (=simplest) subdivision. Arbitrary combinations of these two operators form a class of generalized midpoint subdivsion operators. We analyze the smoothness properties of the pertaining subdivision surfaces using a geometric method and show that the surfaces are C^1 in regular and extraordinary points.

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CP1

Periodic Bézier Curves

We investigate on closed trigonometric curves defined in a Bézier-like fashion. Fourier and Bézier coefficients relate via DFT. In consequence, DFT also applies to several operations, including parameter shift, successive differentiation and degree-elevation. This Bézier model is a particular instance of a general periodic scheme, which also subsumes trigonometric Lagrange interpolation. The Bézier curve defined by certain control points is a low-pass filtered version of the Lagrange curve interpolating the same set of points.

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CP2

Bicubic C2 Polar Subdivision

Popular subdivision algorithms like Catmull-Clark and Loop are C2 almost everywhere, but suffer from shape artifacts and reduced smoothness exactly near the so-called "extraordinary vertices" that motivate their use. Subdivision theory explains that inherently, for standard stationary subdivision algorithms, curvature-continuity and the ability to model all quadratic shapes requires a degree of at least bi-6. The existence of a simple-to-implement C2 subdivision algorithm generating surfaces of good shape and piecewise degree bi-3 in the polar setting is therefore a welcome surprise.

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CP2

An Adaptive Tetrahedral Subdivision Scheme for Finite Element Simulations

We present a subdivision scheme for unstructured tetrahedral meshes inspired by the $\sqrt{3}$-subdivision scheme for triangular meshes. The design emphasizes on geometric quality of the tetrahedral mesh, adaptive refinement, and preserving sharp geometric features on the boundary and in the interior of the physical domain. We demonstrate the versatility of our subdivision scheme for deformation of solid models with elastic material behavior. The underlying mechanical problem is modeled using finite elements. To improve the accuracy of the simulation while saving computational costs, the tetrahedra are adaptively refined according to the internal stresses.

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CP3

The Progressive Iteration Approximation Property

The *progressive iteration approximation* (PIA) property provides an iterative method to build a curve or a surface interpolating a sequence of points in the plane or the space. The convergence of this iterative method depends on the chosen representation. Here we will present a survey of the known results on the PIA, paying special attention to the convergence rate of PIA. Finally, we will show some algebraic techniques which speed up the iterative method.

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CP3

Issues with Multivariate Polynomial Interpolation

One approach to multivariate data interpolation is to select a polynomial basis, construct a Vandermonde matrix for the basis and data points, where the inverse of this matrix gives the polynomial coefficients of the interpolant. In this talk, we show that any fixed choice of basis has corresponding sets of data that result in poor approximations in the interpolant.

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CP3

Nonnegativity Preserving Macro-Element Interpolation

We consider the construction of nonnegative bivariate C^1 interpolants to scattered data using Powell-Sabin and Clough-Tocher macro-element spaces. The presented methods are local, easy to use, and rely on adjusting gradients at the data points to insure nonnegativity of the spline when the original data is nonnegative. We also deal with more general range-restricted interpolation.

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CP4

Fast Hierarchical Discretization of Parametric Surfaces

A surface mesh consists of a set of point samples, which are connected according to some prescribed topology. We introduce a fast and flexible two step meshing technique for parametric surfaces, which first samples the surface using a novel hybrid spatial partitioning, followed by a traversal of the hierarchical structure to establish the mesh topology. Our approach samples the surface enumeratively and independently of meshing according to user defined quality metrics. Therefore, we can efficiently generate large multi-resolution point clouds, which we store in a hybrid binary quaternary tree structure that is ideally suited for downstream applications. Our hybrid spatial partitioning algorithm can produce high quality structured meshes of well shaped triangles according to user defined rules, and is several orders of magnitude faster than popular search based meshing algorithms.

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CP4

Streaming Surface Reconstruction Using Wavelets

We present a streaming method for reconstructing surfaces from large data sets generated by a laser range scanner using wavelets. Wavelets provide a localized, multiresolution representation of functions and this makes them ideal candidates for streaming surface reconstruction algorithms. We show how wavelets can be used to reconstruct the indicator function of a shape from a cloud of points with associated normals. Our method proceeds in several steps. We first compute a low-resolution approximation of the indicator function using an octree followed by a second pass that incrementally adds fine resolution details. The indicator function is then smoothed using a modified octree convolution step and contoured to produce the final surface. Due to the local, multiresolution nature of wavelets, our approach results in an algorithm over 10 times faster than previous methods and can process extremely large data sets in the order of several hundred million points in only an hour.

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CP4

Real-Time Triangulation of Point Streams

Hand-held laser scanners are used massively in industry for reverse engineering and quality measurements. In this process, it is difficult for the human operator to scan the target object completely and uniformly without an interactive triangulation. In this talk we present a real-time triangulation approach for point streams, that computes a triangulation of the data points as they are received from the laser scanner. Multiple scanned areas and areas with a higher point density result in a finer mesh and a higher accuracy. On the other hand, the vertex density adapts to the estimated surface curvature. To assist the human operator the resulting triangulation is rendered with a visualization of its faithfulness and the display of an optimal scanning direction.

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CP5

Towards Design Automation of Customized Hearing Aid Devices

According to the National Institute of Health (NIH), more people today are loosing their hearing earlier in life. In order to respond to the growing demand and higher quality requirements, the hearing industry is undergoing a fundamental transformation: from tedious fully manual process, through computer aided design and manufacturing (CAD/CAM), towards fully automatic "on-the-desk" solutions in the future. To support this change, innovative design approaches are currently being developed in the hearing industry. The ongoing research effort, which is focused on automation of the hearing aid design process, will be presented. The corner stone of the successful design automation is smart and efficient shape optimization algorithms, that would not only take into account geometry constraints, but would also consider the performance of the real device. Such optimization will be illustrated on design of ventilation tube inside the hearing aid. Another important component of the presented research is an automatic detection of anatomic features on the impression surface. Current work instructions for human operators are based on these features. Consequently, automatic detection of the features will allow translation of the vague work instructions into precise computer scripts. Finally, initial results of the shape space parametrization of the human ear canals will be presented. These results exhibit strong correlation between the shape of the ear and the modeling operations applied. This correlation inspires future research towards an ambitious goal of developing intelligent design system, which will learn from previously delivered products in order to produce new designs.

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CP5
Topological Modeling for Movies and Simulations

Is topology relevant for modeling algorithms for the motion picture industry? for simulating explosions? Yes. Kerner Graphics, Inc., is developing algorithms for those purposes, as partially funded through the NSF SBIR program. Some of that work will be described.

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CP5
Physical Markup Language, Strategies, and Algorithms for Virtual Content Creation

Creating virtual content is cumbersome and time consuming. We describe FXPALs novel approach to creating virtual models from images in which users have marked up rooms or objects with physical markers that have associated meanings drawn from a markup language. We present improvements and extensions to our markup language, user markup strategies, and our algorithms for determining the model, particularly its geometry, from the marker positions, orientations, and associated semantic information.

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CP6
Precise Hausdorff Distance Computation Between Polygonal Meshes

We present an efficient algorithm for computing the precise Hausdorff distance between two non-convex polyhedra represented as triangular meshes. The locus of candidate points, events where the Hausdorff distance may occur, is fully classified. These events include simple cases where two vertices of the two meshes are examined as well as cases of extreme distance evaluation of the intersection curve between a self-bisector of one mesh and the other mesh. The computation of all self-bisectors of every pair of primitives (i.e. vertex, edge, or face) are analytically constructed and intersected, yielding a set of conical curve segments.

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CP6
Detecting Spline Surface Intersections Using Heterogeneous Computers

A modern PC has evolved to a heterogeneous system, equipped with both a multi-core CPU and a graphics processing unit (GPU). We present a method for detecting spline surface intersections exploiting the strengths of the different processing elements in such a system. The algorithm is designed towards good scalability, solving the problem within a prescribed level of accuracy. Results show a speedup exceeding one order of magnitude compared to a traditional algorithm using a CPU.

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CP6
GPU Accellerated Approximative Implicitzation

Recent years have shown a tremendous development in graphics processing unit (GPU) hardware. From initially being designed for discrete graphics, they are now used in a wide area of applications, with speed-ups of 10–50 times over traditional CPUs. This talk discusses the use of GPUs to speed up approximative implicitization. Approximative implicitization is a computationally demanding algorithm that finds the best, in a least squares sense, implicit representation of a curve or surface.

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CP6
Computing the Distance of Closest Approach Between Ellipses and Ellipsoids

The distance of closest approach of two arbitrary separated ellipses is the distance among their centers when they are externally tangent after moving them through the line joining their centers. This is a critical problem when modeling and simulating systems of anisometric particles such as liquid crystals. We introduce a new analytic approach computing the distance of closest approach for ellipses and ellipsoids improving the solution for ellipses in [X. Zheng, P. Palffy-Muhoray, Distance of closest approach of two arbitrary hard ellipses in two dimensions, Physical Review E, 2007]. The distance of closest approach does only depend on the computation of the smallest positive real root of a degree four, for ellipses, and eight, for ellipsoids, univariate polynomial.

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CP6
A Hierarchical Data Structure for Piecewise Linear Functions

Binary space partition (BSP) trees are the most general spatial indexing data structure. Motivated by a connection between BSP tree merging and linear programming, this talk considers a modification of BSP trees for efficiently representing piecewise linear functions. This new data structure expands and unifies the capabilities of BSP trees with Binary Decision Diagrams giving an analogous suite of operations.

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CP6
Smooth Separating Surfaces for Binary Rectilinear Data Sets

Segmentation techniques applied to rectilinear volume data sets result in lattice points marked as belonging or not belonging to an object of interest. We describe a new method of computing a polygon surface which bounds the lattice points of the object. This surface has the unique property of locally being a single valued function. This latter property is exploited in the development of methods for smoothing the polygon surface while maintaining its separating properties.

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MS1
Future Research Challenges for a Government Lab

The modeling and simulation potential continues to be greater than actually realized in many design environments. Moving developed M&S capabilities into the design cycle faces ominous technical and practical obstacles. Although CAD systems claim ubiquitous customization and integration ability, moving advanced M&S into these environments is both tedious and complex - especially if some form of automation is desirable. Hand-rolled systems lack geometric sophistication for design definition. This initial investment cost for M&S supported design systems has to be reduced significantly to allow lower-volume design environments to be practicable. Key technologies that must command more attention include geometric defeaturing, quicker and easier idealizations and geometry-tolerant meshing algorithms. Practical advances that would have a strong impact include better access to live CAD geoemetry and parameters, simpler integration tools, and exploration of more creative business development scenarios.

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MS1
Problems for 3D Internet

The driving forces for 3D Internet technology seem to be focused on 3D images and tessellated shape representations. Consequently the 3D representation is voluminous and the user quality of experience lags far behind the one of installed 3D applications using higher order shape representations. As wireless data transmission consumes much energy, compact higher order shape representations will be more energy efficient and have much to offer to future 3D Internet applications especially for mobile devices.

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MS1
Computing Derivatives of Engineering Analysis Results with Respect to Design Parameters

Performing design and shape optimization effectively requires computing derivatives of engineering analysis quantities used in objective functions and constraints with respect to top level design parameters. Various approaches have been taken to solve specific instances of the general problem. One approach employed by Samareh and others involves taking advantage of mesh-based analysis codes and derivatives computed by adjoints. More recently, Shapiro and Suresh and their students have taken a more direct and potentially more promising approach. These steps offer promise that the general problem may soon be solved.

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MS1
Capturing Design Intent in Free Form Surfacing

We will discuss design intent, and how it applies to free form surfacing. We then present some work that is being done in this area by SolidWorks Research and pose some other potential areas of research.

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MS1
3D Shapes and Semantics - A Research Roadmap

Being Drafted in an EU Project

The 8 teams of the EU coordination action FOCUS K3D (see the web site www.focusk3d.eu) have been charged to write a research roadmap for the use of semantics in 3D content modelling and processing. The presentation will report on the project's goals, activities, and results so far. The four application areas considered in the project are Bioinformatics & Medicine, Gaming & Simulation, Cultural Heritage, and CAD/CAM & Virtual Product Modelling, with this presentation specifically addressing the latter.

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MS1

Problems in Architectural Geometry

Freeform structures have been used in architecture for a long time, e.g. by means of form-finding. Nowadays architects use freeform surfaces more freely. The occurring geometrical problems resulted in a new field of research called *Architectural Geometry*. Its topics include the geometrical simplification of freeform surfaces, the link to CAM and production aware design tools. We will give an introduction to the state of the art as well as to future challenges to be met.

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MS2

Preparing Biological Imaging-derived Data for Geometric Analysis and Mesh Generation

Images generated from biological data can present a modeler with a wide spectrum of challenges. The surface shapes to reconstruct can be highly complex and vary widely across different datasets. In addition, the quality of the dataset may suffer from a range of inconsistencies artificially differentiating it from the actual specimen. We present methods for addressing these challenges prior to mesh generation and geometric analysis, thus significantly increasing confidence in the resulting mesh.

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MS2

Toward Real-Time Image-to-Mesh Conversion for Image Guided Neurosurgery

In this talk we will: (1) briefly survey the current state of the art approaches to tetrahedral mesh generation from medical image data, (2) analyze mesh generation requirements of non-rigid registration (NRR) for image guided neurosurgery, (3) briefly describe our efforts for real-time image-to-mesh conversion for NRR, and (4) compare the performance of different meshers in the NRR context using generic and application-specific quantitative measures.

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MS2

Geometric Processing and Mesh Generation of Imaging-Derived Biomedical Data

We present a suite of novel algorithms for processing imaging-derived data for biomedical simulations. Our algorithms include: 1) efficient and robust generation of centerlines from a surface mesh (such as a respiratory isosurface); 2) automatic identification and truncation of outlets of meshes based on the stable tips of the centerline for imposing boundary conditions; and 3) generation of high-quality, hybrid prismatic/tetrahedral meshes for flow simulations. We employ these methods to generate computable grid, and demonstrate some unprecedented results with up to 40,000 airways for the rodent images.

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MS2

Accurate Extraction of Morphological Information from Volumetric Imagery

In order to accurately analyze the flow of blood in any organ, detailed morphometric data, such as diameters, lengths, or branching patterns, of the organs vasculature is required. Deriving this information manually is a very labor intensive process. The amount of labor can be significantly reduced by utilizing tools that mostly automatically extract such information from volumetric imagery. Hence, we will present methodologies that perform this task at a very high level of accuracy.

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MS3

Topologically Correct Surface Reconstruction in

Presence of Boundaries

We present an algorithm for the reconstruction of a surface with boundaries (including a non-orientable one) from a sufficiently dense sample. It is guaranteed that the output is isotopic to the unknown sampled surface. No previously known algorithm guarantees isotopic or homeomorphic reconstruction of surfaces in presence of boundaries. The algorithm is surprisingly simple. It 'peels' slivers greedily from an α-complex of a sample of the surface. No other post-processing is necessary. We provide several experimental results from an implementation of the basic algorithm and also a modified version of it.

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MS3
Measuring with Persistent Homology

Persistent homology is an algebraic method for measuring the scale of a homology class in a filtration. Taking the sublevel sets of a real-valued function, we get a measure on the features that develop as we increase the threshold. This bridge between algebra and measure theory is solidified by results about the stability of the diagram we use to express persistence. We illustrate the framework with applications to geometric modeling.

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MS3
Discrete Geometry Processing with Topological Guarantees

Our goal is to compute reliable solutions for many nonlinear geometric problems that arise in geometric modeling, computer graphics and robotics. Prior exact algorithms for such problems are able to guarantee correct output, but are usually difficult to implement reliably and efficiently. On the other hand, current approximate techniques may not provide any topological guarantees on the solution. We bridge the gap between these two approaches, by developing a unified sampling based approach to solve these problems with topological guarantees. Specifcally, we present results for surface extraction and motion planning problems. Surface extraction problems include Boolean operations, implicit surface polygonization and Minkowski sum evaluation. Moreover, we present an algorithm for complete motion planning, i.e., find a path if one exists and report a failure otherwise.

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MS3
Multi-Scale Morse Theory for Science Discovery

Advanced techniques for visualization and understanding of large scale data sets are a crucial component of the modern science discovery process. In this talk, I will present a robust topological framework designed for quantitative analysis and exploration of massive scientific models. The inherent robustness of our combinatorial algorithms allows us to address the high complexity of the feature extraction problem for terascale data. I will discuss how our system has enabled the first successful quantitative analysis of several massively parallel simulations including the evolution of the mixing layer of hydrodynamic instabilities, the structural properties of porous media under stress and failure, and the turbulence hydrogen flames in clean combustion devices.

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MS3
Specification and Validation of Tolerant Solid Models

The mismatch between geometry / topology in a boundary representation of solid models is the key cause of problems in geometric data quality. Tolerant solid modeling attempts to resolve these difficulties by associating tolerance zones with vertices, edges, and faces of the boundary representations. We propose formal models for specifying tolerant models and for validating tolerant boundary representations. In particular, we define the notion of topological consistency between geometry and topology in a tolerant model, and propose a general and efficient algorithm for verifying this consistency. Our approach is consistent with the classical solid modeling and subsumes several previous approach to tolerant solid modeling.

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MS3
Robust Solid Modeling: An Industrial Perspective

A major commercial solid modeler, such as ACIS®, is asked to perform many millions of solid modeling operations every year. This gives, through failure reports, commercial development organizations large suites of low-probability, real world "corner-case" models and operations which stress the modeler's algorithms. I will discuss, from both theoretical and practical viewpoints, some of the failure modes in modeling operations that the ACIS development organization has observed over the years and techniques for avoiding them.

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MS4
Challenges in Geometric Analysis and Processing of Biomedical Geometries

We present a survey of biomedical topics that exemplify present and future challenges in biomedical computational geometry, with the aim of stimulating consensus and discussion. Geometry topics will include mesh generation, registration and management for fluid, solid and fluid-solid interaction simulations, multiscale analysis, mapping, storage, simplification and communication. Biomedical topics will include, tissue lamination, the importances of interfaces in biology, matching cell type and expression with computed field variables, physiological boundary conditions, atlases and morphometry.

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MS4
High-Quality, Scale-Invariant, Layered Tetrahedral Grids for Biomedical Computing

We present an automated meshing algorithm for generating anisotropic layered tetrahedral meshes on arbitrary biological geometries, with the number of layers and the desired element anisotropy for each phase as the only input parameters. Surface densities are adapted to the gradient-limited local feature size such that meshes will tend to have relative error equilibrated over the whole mesh. Layering is important in most biological geometries to model tissue and fluid lamination.

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MS4
Surface Reconstruction From Non-parallel Curve Networks

We introduce an algorithm that is capable of reconstructing surface from planar cross-sectional curve networks of arbitrary shape and topology. The input data may lie on non-parallel cross-sections and consist of curve networks that represent the segmentation of the underlying object by different material or tissue types (e.g., skin, muscle, bone, etc.) on each cross-section. We also develop a novel interface for modeling surfaces from volume data by allowing the user to sketch contours.

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MS4
Mesh Generation for Complex Biological Geometry

Complex geometry extracted from 3D image data or acquired from 3D scanning can be of many forms of deficiencies. To repair such deficiencies and generate high quality meshes for simulations are often tedious and challenging. This presentation will cover the approaches developed at the Enabling Technology Laboratory to address some of the geometry repair issues and the mesh generation technologies to generate high quality tetrahedral, hybrid and hexahedral meshes associated with such complex geometry. Generation of high fidelity human airway will also be discussed in this presentation to identify the challenges in geometry and mesh generation processes associated with complex biological geometry.

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MS4
Adaptive Mesh Generation for Viral Capsid from EM Data

Electron Microscopy data for viruses has been largely obtained by single particle technique and stored in a repository of EMDB by many research groups around the world. One preliminary step is to study the structure of virus for further medicine design. We want to first produce a good adaptive mesh for virus capsid. Combining the improved Marching Cube method with dual contouring method, an adaptive, intersection-free, manifold mesh based on octree data structure is produced for further structure study.

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MS5
Procedural Methods: Current Trends and Challenges

Research in procedural methods has shifted its focus from height-map generation, in its early years, towards increasingly complex and realistic urban environments, nowadays. We briefly discuss the main current challenges, including (i) the GPU-based quest for performance and interactivity improvement, (ii) the realism leap of deploying more and more semantics in both the procedural generation process and the generated models, and above all, (iii) the integration of the huge variety of procedural methods within some framework.

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MS5

Procedural Street Network Modeling for Urban Environment

Street network design is one of the earliest stages in urban planning. The quality and flexibility of street networks greatly impact the subsequent stages of city planning. There have been a number of approaches in procedural modeling of street networks with applications in games, movies and training. We describe recent developments in achieving interactive procedural generation of street networks. The main idea is to design a tensor field and use hyperstreamlines following the tensor field to produce the street networks. This method is fast and provides hierarchical control.

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MS5

Terrain Generation: Beyond Fractal Noise

Terrain generation has been a favorite topic within procedural modeling from its inception. This presentation discusses the classic noise algorithms, height-map filters, thermal and fluvial erosion and the formation of river stream networks. Moreover, recent advances in GPU-based parallel programming have enabled high-speed noise algorithms and even real-time simulations of erosion processes. Interactive procedural terrain editors are now being developed that integrate terrain generation methods in the virtual world design process in a user friendly and effective way.

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MS5

Inside Buildings

Hand-modeling the inside of all buildings in a virtual world is a long and cumbersome task. Aided by procedural generation techniques, this task can be alleviated. Numerous techniques, e.g. shape grammar techniques and graph-based approaches, have been developed to generate floor plans of buildings, some of which can be used to generate building interiors on the fly. Using layout solving methods, the interiors can then be filled with relevant objects.

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MS6

Non-uniform Tetrahedral Subdivision

A non-uniformal tetrahedral subdivision scheme inspired by the $\sqrt{3}$-subdivision scheme for triangular meshes is presented. In contrast to existing tetrahedral subdivision schemes, both, adaptive refinement and preservation of sharp features, are supported. Furthermore, the proposed refinement operator generates only tetrahedra and no additional octahedra, as edge bisections are avoided. Our algorithm is motivated primarily by the need to generate high-quality adaptive tetrahedral meshes for numerical simulations and visualization of scientific phenomena.

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MS6

NURBS with Extraordinary Points: High-degree, Non-uniform, Rational Subdivision Schemes

We present a subdivision framework that adds extraordinary points to NURBS of arbitrarily high degree. The surfaces can represent any NURBS patch exactly. Our rules handle non-uniform knot vectors, and are not restricted to midpoint knot insertion. In the absence of multiple knots at extraordinary points, the limit surfaces have bounded curvature.

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MS6

Nonlinear Lane-Riesenfeld Algorithms with Nonlinear Averaging Rules: The Functional Setting

We investigate the convergence of the Lane-Riesenfeld subdivision algorithm for uniform B-splines, when the arithmetic mean is replaced by a different nonlinear, symmetric, binary averaging rule in each step of the algorithm. We review the notion of a symmetric binary averaging rule, derive some of its properties, and present canonical examples. We then provide sufficient conditions on nonlinear averaging rules that guarantee convergence of the Lane-Riesenfeld algorithm to either a continuous or a smooth function.

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MS6

Dinus: Double Insertion, Non-Uniform, Stationary Subdivision Surfaces

In this talk we will present our new Double Insertion, Non-Uniform, Stationary Subdivision Surfaces, called DINUS. DINUS are a generalization of non-uniform bicubic spline surfaces and Catmull-Clark subdivision surfaces. Arbitrary knot intervals on the edges, special features, and limit point as well as limit normal rules are some of the prominent features of the DINUS. To demonstrate the usability, we implemented the DINUS as Autodesk Maya Plugin.

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MS7

Analysis-aware Modeling: Representing Shape and Volume

Isogeometric analysis has been proposed as a methodology for bridging the gap between Computer Aided Design (CAD) and Finite Element Analysis (FEA). Current shape modeling systems create boundary representations, but in order to support full 3D isogeometric analysis, the representations, modeling methodologies, and design operations must be generalized to create suitable trivariate representations. This presentation discusses and demonstrates initial modeling methodologies towards this new paradigm.

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MS7

Challenges of Isogeometric Representation for CAD

Isogeometric analysis uses volumetric NURBS elements rather than traditional finite elements for analysis. NURBS represent elementary shapes such as sphere, cylinders, and torus exactly. Used in analysis NURBS offers exact geometry representation, simplified design optimization and tighter integration of analysis and CAD. In this talk we address different aspects of isogeometric representation and analysis with a main focus on the relation to CAD, and how CAD can change to improve analysis by incorporating isogeometric representation.

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MS7

Analysis-aware Modeling: Model Quality

A long term goal of Isogeometric analysis is to unify Computer Aided Design (CAD) and Finite Element Analysis (FEA). We demonstrate that in a similar way as how mesh quality is used in traditional FEA to help characterize the impact of the mesh on analysis, an analogous concept of model quality exists within isogeometric analysis. The consequence of these observations is the need for a new area within modeling : analysis-aware modeling.

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MS7

NURBS Volume Parameterizations for Blades

Isogeometric Analysis uses NURBS $nonuniformrationalB-spline$ representations of the domain for performing numerical simulations. We present a method for generating NURBS parameterizations for the class of swept volumes. These are obtained by sweeping a planar shape, which is parameterized as a surface patch, through three-dimensional space. The class of these volumes covers a number of interesting free-form shapes, such as blades for turbines and propellers, ship hulls or wings of airplanes.

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MS8

A Surprisingly Smooth MRA on the (Riemann) Sphere Based on Box-spline and Subdivision, with Applications

The Loop subdivision scheme is, at the regular part, based on the box-spline with the three directions [1,0],[0,1],[1,1] each repeated twice. The scheme is not C^2 smooth at the extraordinary vertices and there is a theorem by Reif and

Prautzsch that says that there is no simple way to tinker the Loop scheme to make it C^2, except maybe in the case of valence 3 extraordinary vertex. The Reif-Prautzsch theorem is inconclusive about the valence 3 case. Perhaps surprisingly, using the box-spline with the three directions [1,0],[0,1],[1,1] each repeated thrice at the regular part, one can create a perfectly C^2 subdivision rule at a valence 3 vertex. Moreover, the characteristic map of the resulted scheme has a elegantly simple form which coincides with a known structure in the study of Riemann surfaces. This result allows one to efficiently approximate smooth functions defined on a genus 0 surface using subdivision. We discuss potential applications to (a) smoothing splines on a genus 0 domain, and (b) spherical conformal parametrization.

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MS8

Discrete Surface Curvature Flow

Ricci flow is the process to deform the Riemannian metric proportional to the Ricci curvature, such that the curvature evolves according to a heat diffusion. Surface Ricci flow is a powerful tool to design a conformal Riemannian metric of the surface with prescribed Gaussian curvature. The theory and algorithm for discrete Ricci flow is introduced in this work for discrete surfaces with both Euclidean and hyperbolic background geometries. Its applications in engineering fields will be briefly discussed.

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MS8

Spherical Wavelets of Local Support Using the HEALPix Grid

We recently saw a huge leap in the resolution of geopotential data with the release of a new global geopotential model resolved to spherical harmonic 2160. This rich dataset can be used in a wide range of navigational and earth sciences applications, but is extremely unwieldy to work with using classical spherical harmonics. With DARPA/ NGA support we have developed a new wavelet transform for such data by cross-applying a coordinate system for the sphere - HEALPix - which is already popular in cosmology. This Healpix wavelet transform offers smooth wavelets of compact support and is based on a new type of two- scale refinement scheme which can exploit HEALPix's 'sweet and sour' mix of analytic area-preserving coordinates together with singularities at certain points and lines. The new refinement scheme makes it possible to efficiently represent smooth functions on the sphere without artifacts at the tropical lines, Greenwhich meridan, or poles. With the HEALPIx wavelet expansion, we can now compress a global geopotential model far more severely, for a given degree of allowable distortion, than spherical harmonics, and we can now evaluate a field quantity at a single point dramatically faster than with traditional spherical harmonics. The wavelet coefficients of the geopotential have statistical properties paralleling those previously observed for wavelet coefficients of natural images. These include generalized Gaussian distributions with exponent significantly smaller than 1 and parent- child correlations in variances.

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MS8

On Subdivision Methods of Manifold-valued Data

In recent years, many results on subdivision methods of manifold-valued data were developed. These results teach us how tricky much trickier than we (David Donoho, Nira Dyn, Peter Schroder and others) first thought 5-10 years ago – it is to take a linear subdivision scheme and adapt it to manifold valued data. In this talk, I will state the problem, the criteria for a good solution, the known results discovered by us, the ongoing research and the open problems. (Joint work with Gang Xie and Esfandiar Navayazdani.)

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MS9

Advances in the Error Analysis for Isogeometric Discretization Techniques

We present new results in the error analysis for isogeometric discretization techniques with a special attention to electromagnetic problems. We develop estimates which are explicit with respect to the mesh h and the degree p used for the discretization. Our analysis is restricted to families of discrete spaces which have at most $(p+1)/2$ continuous derivatives across the inter-element boundaries.

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MS9

Isogeometric Analysis: Toward Integration of CAD and FEA

The initial work in isogeometric analysis was motivated by the gap between the worlds of finite element analysis (FEA) and computer aided design (CAD). As the number of people involved with isogeometric analysis from both communities has grown, this gap has become increasingly apparent to all involved. It is not only a shortcoming of current technology but of the entire engineering process. Technological barriers are often easier to overcome than the inertia of status quo.

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MS9

Towards an Isogeometric Toolkit

Traditional CAD-type toolkits support only volumes described by inner and outer shells composed of patchworks of surface pieces. An isogeometric toolkit has to support 3D shapes described by structures of parametric trivariate NURBS objects. This poses new requirements to data structures, and methods for shape design and shape interrogation. The talk will present selected results from requirement analysis to an isogeometric toolkit being developed. The main focus will be on shape related issues.

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PP0

Semantic-Based Partial Retrieval of Cad Models for Design Reuse

In this paper, we present a semantic-based partial retrieval approach of CAD models for design reuse. Based on the observation of reusable regions for design of 3D CAD models, for each model in the model library, we propose an algorithm that automatically extracts its reusable regions for partial retrieval. To further effectively support the partial retrieval of these reusable regions through simple queries, we represent each reusable region by all its local matching regions and describe each local matching region in a hierarchical way. Based on the hierarchical descriptor, a partial retrieval method for reusable regions is put forward. The approach proposed is implemented and tested by hundreds of mechanical parts. Preliminary results show that the method can effectively support partial retrieval for design reuse.

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PP0

Anisotropic Resizing of Model with Geometric Textures

Model resizing is a useful technique for model reuse. Introduced by Kraevoy et al., non-homogeneous model resizing is able to preserve important geometric features during anisotropic scaling. However, many practical objects contain various geometric textures. Different from similar objects without geometric textures, such objects seem as if extremely difficult to resize even if the underlying surfaces are relatively simple. In this paper, we present an automatic model resizing method based on geometric texture transfer. Geometric textures are separated from the underlying surfaces and reproduced on the non-homogenously scaled surfaces using geometric texture synthesis. By utilizing the natural correspondence between the surfaces before and after resizing, surfaces with multiple geometric textures can be resized and geometric texture recovered automatically. Experimental results show that our method effectively and automatically preserves geometric textures during the model resizing process.

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PP0

Hierarchical Molecular Interfaces and Solvation Electrostatics

Electrostatic interactions play a significant role in determining the binding affinity of molecules and drugs. While significant effort has been devoted to the accurate computation of biomolecular electrostatics based on an all-atomic solution of the Poisson-Boltzmann (PB) equation for smaller proteins and nucleic acids, relatively little has been done to optimize the efficiency of electrostatic energetics and force computations of macromolecules at varying resolutions (also called coarse-graining). We have developed an efficient and comprehensive framework for computing coarse-grained PB electrostatic potentials, polarization energetics and forces for smooth multi-resolution representations of almost all molecular structures, available in the PDB. Important aspects of our framework include the use of variational methods for generating C^2-smooth and multi-resolution molecular surfaces (as dielectric interfaces), a parameterization and discretization of the PB equation using an algebraic spline boundary element method, and the rapid estimation of the electrostatic energetics and forces using a kernel independent fast multipole method. We present details of our implementation (PB-CFMP), as well as several performance results on a number of examples.

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PP0

Mesh Clustering by Approximating Centroidal

Voronoi Tessellation

An elegant and efficient mesh clustering algorithm is presented. The faces of a polygonal mesh are divided into different clusters for mesh coarsening purpose by approximating the Centroidal Voronoi Tessellation of the mesh. The mesh coarsening process after clustering can be done in an isotropic or anisotropic fashion. The presented algorithm improves previous techniques in local geometric operations and parallel updates. The new algorithm is very simple but is guaranteed to converge, and generates better approximating meshes with the same computation cost. Moreover, the new algorithm is suitable for the variational shape approximation problem with $L^{2,1}$ distortion error metric and the convergence is guaranteed. Examples demonstrating efficiency of the new algorithm are also included in the paper.

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PP0
Geometric Reasoning Via Internet CrowdSourcing

The ability to interpret and reason about shapes is a peculiarly human capability that has proven difficult to reproduce algorithmically. So despite the fact that geometric modeling technology has made significant advances in the representation, display and modification of shapes, there have only been incremental advances in geometric reasoning. For example, although today's CAD systems can confidently identify isolated cylindrical holes, they struggle with more ambiguous tasks such as the identification of partial symmetries or similarities in arbitrary geometries. Even well defined problems such as 2D shape nesting or 3D packing generally resist elegant solution and rely instead on brute force explorations of a subset of the many possible solutions. Identifying economic ways to solving such problems would result in significant productivity gains across a wide range of industrial applications. The authors hypothesize that Internet Crowdsourcing might provide a pragmatic way of removing many geometric reasoning bottlenecks. This paper reports the results of experiments conducted with Amazons mTurk site and designed to determine the feasibility of using Internet Crowdsourcing to carry out geometric reasoning tasks as well as establish some benchmark data for the quality, speed and costs of using this approach. After describing the general architecture and terminology of the mTurk Crowdsourcing system, the paper details the implementation and results of the following three investigations; 1) the identification of 'Canonical' viewpoints for individual shapes, 2) the quantification of 'similarity' relationships with-in collections of 3D models and 3) the efficient packing of 2D Strips into rectangular areas. The paper concludes with a discussion of the possibilities and limitations of the approach.

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PP0
Gabriel Meshes and Delaunay Edge Flips

We undertake a study of the local properties of 2-Gabriel meshes: manifold triangle meshes each of whose faces has an open Euclidean diametric ball that contains no mesh vertices. We show that, under mild constraints on the dihedral angles, such meshes are Delaunay meshes: the open geodesic circumdisk of each face contains no mesh vertex. The analysis is done by means of the Delaunay edge flipping algorithm and it reveals the details of the distinction between these two mesh structures. In particular we observe that the obstructions which prohibit the existence of Gabriel meshes as homeomorphic representatives of smooth surfaces do not hinder the construction of Delaunay meshes.

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PP0
Robust Principal Curvatures Using Feature Adapted Integral Invariants

Principal curvatures and principal directions are fundamental local geometric properties. They are well defined on smooth surfaces. However, due to the nature as higher order differential quantities, they are known to be sensitive to noise. A recent work by Yang et al. combines principal component analysis with integral invariants and computes robust principal curvatures on multiple scales. Although the freedom of choosing the radius gives results on different scales, in practice it is not an easy task to choose the most appropriate for an arbitrary given model. Worse still, if the model contains features of different scales, a single does not work well at all. In this work, we propose a scheme to automatically assign appropriate radii across the surface based on local surface characteristics. The radius is not constant and adapts to the scale of local features. An efficient, iterative algorithm is used to approach the optimal assignment and the partition of unity is incorporated to smoothly combine the results with different radii. In this way, we can achieve a better balance between the robustness and the accuracy of feature locations. We demonstrate the effectiveness of our approach with robust principal direction field computation and feature extraction.

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PP0

Interrogating Witnesses for Geometric Constraint Solving

Classically, geometric constraint solvers use graph-based methods to analyze systems of geometric constraints. These methods have intrinsic limitations, which the witness method overcomes. This paper details the computation of a basis of the vector space of the free infinitesimal motions of a typical witness, and explains how to use this basis to interrogate the witness for detecting all dependencies between constraints: structural dependencies already detectable by graph-based methods, and also non-structural dependencies, due to known or unknown geometric theorems, which are undetectable with graph-based methods. The paper also discusses how to decide about the rigidity of a witness.

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PP0

Stable Mesh Decimation

Quality mesh decimation has been an ongoing endeavor as researchers attempt to simulate and analyze functions defined relative to gigantic meshes created by automated processes. Current mesh reduction techniques, while numerous, all primarily reduce mesh size by successive element deletion (e.g. edge collapses) with the goal of geometric and topological feature preservation. The choice of geometric error used to guide the reduction process is chosen independent of the function the end user aims to calculate, analyze, or adaptively refine. In this paper, we argue that such a decoupling of structure from function modeling is often unwise as small changes in geometry may cause large changes in the associated function. A stable approach to mesh decimation, therefore, ought to be guided primarily by an analysis of functional sensitivity, a property dependent on both the particular application and the equations used for computation (e.g. integrals, derivatives, or integral/partial differential equations equations). We present a methodology to elucidate the geometry sensitivity to functionals thereby deriving more applicabile cost functions for the decimation procedure. In doing so we additionally resort to functional discretization techniques, namely, Galerkin finite element and discrete exterior calculus methods. We present a number of examples illustrating this methodology and provide numerical examples to further substantiate our choices.

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PP0

An Isogeometric BEM for Exterior Potential-Flow Problems in the Plane

In this paper, the isogeometric concept introduced by Hughes, in the context of Finite Element Method, is applied to Boundary Element Method (BEM), for solving an exterior planar Neumann problem. The developed isogeometric-BEM concept is based on NURBS, for representing the exact body geometry and employs the same basis for representing the potential and/or the density of the single layer. In order to examine the accuracy of the scheme, numerical results for the case of a circle and a freeform body are presented and compared against analytical solutions. This enables performing a numerical error analysis, verifying the superior convergence rate of the isogeometric BEM versus low-order BEM. When starting from the initial NURBS representation of the geometry and then using knot insertion for refinement of the NURBS basis, the achieved rate of convergence is $O(DoF^{-4})$. This rate may be further improved by using a degree-elevated initial NURBS representation of the geometry (kh-refinement).

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PP0

C^∞ Smooth Freeform Surfaces Over Hyperbolic Domains

Constructing smooth freeform surfaces of arbitrary topology with higher order continuity is one of the most fundamental problems in shape and solid modeling. Most real-world surfaces are with negative Euler characteristic number $\chi = 2-2g-b < 0$, where g is genus, b is the number of boundaries. This paper articulates a novel method to construct C^∞ smooth surfaces with negative Euler numbers based on hyperbolic geometry and discrete curvature flow. According to Riemann uniformization theorem, every surface with negative Euler number has a unique conformal Riemannian metric, which induces Gaussian curvature of -1 everywhere. Hence, the surface admits hyperbolic geometry. Such uniformization metric can be computed using the discrete curvature flow method: hyperbolic Ricci flow. Consequently, the basis function for each control point can be naturally defined over a hyperbolic disk, and through the use of partition-of-unity, we build a freeform surface directly over hyperbolic domains while having C^∞ property. The use of radial, exponential basis functions gives rise to a true meshless method for modeling freeform surfaces with greatest flexibilities, without worrying about control point connectivity. Our algorithm is general for arbitrary surfaces with negative Euler characteristic. Furthermore, it is C^∞ continuous everywhere across the entire hyperbolic domain without singularities. Our experimental results demonstrate the efficiency and efficacy of the proposed new approach for shape and solid modeling.

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Solving Global Geometric Constraints on Free-Form Curves

Constraint-based geometric modeling is the standard modeling paradigm in current modern CAD systems. Generally, the user defines constraints on the geometric objects and a solver is applied to find a configuration of the geometry, which satisfies these constraints. Proper application of these constraints allows rapid modification of the geometry without loss of design intent. However, in current CAD systems, constraint solving for free-form geometric objects is generally limited. In particular, constraining global features such as limits on a curve's curvature values, are not supported. In this paper we present a general method, within the constraint-based framework, to construct global constraints on free-form curves. The method starts by defining sufficient conditions on the curves in terms of an inequality expression, unlike local constraints the global constraint expression will be defined for all the domain of the curves. We then transform the expression into a symbolic polynomial, whose coefficients are symbolic expressions of the original curves. In the final step, a set of inequality constraints is applied in terms of the symbolic coefficients. These inequality constraints enforce the positivity of the symbolic polynomial. The final inequality constraints are fed into the solver along with any other local constraints, which the user has provided on the curves. Therefore, the solution returned by the solver satisfies both the global constraints and any other local constraints the user supplies. We have implemented a prototype of our method using existing commercial constraint solvers. We present results on several problems, which are handled as global geometric constraints using our method.

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Efficient Computation of a Near-Optimal Primary Parting Line

In injection molding, a flat parting surface that is normal to the mold parting direction achieves the best mold alignment with the least cost. However, for complex parts, parting surfaces that consist of a number of planes are necessary. In this paper, we provide an algorithm to find a near-optimal parting surface as a series of planes that intersect the boundary of the part. We form a continuous band of triangles on the part boundary that are parallel to the parting direction within a tolerance and perform vertical trapezoidation of the band. We can then find a set of planes that intersect vertical lines in the trapezoidation. We use a linear program to keep the planes normal to the parting direction.

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Reliable Sweeps

We present a simple algorithm to generate a topology-preserving, error-bounded approximation of the outer boundary of the volume swept by a polyhedron along a parametric trajectory. Our approach uses a volumetric method that generates an adaptive volumetric grid, computes signed distance on the grid points, and extracts an isosurface from the distance field. In order to guarantee geometric and topological bounds, we present a novel sampling and front propagation algorithm for adaptive grid generation. We highlight the performance of our algorithm on many complex benchmarks that arise in geometric and solid modeling, motion planning and CNC milling applications. To the best of our knowledge, this is the first practical algorithm that can generate swept volume approximations with geometric and topological guarantees on complex polyhedral models swept along any parametric trajectory.

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Computer Aided Design and Evaluation of New Anatomic Fixation System on Entire Pelvic Model

This paper presented a special computer aided procedure to design a new sacroliliac anatomic bar-plate internal fixation system, and evaluated its biomechanical properties on an accurate patient-specific finite element model of entire pelvis, compared with two conventional internal fixation methods. Based on virtual anatomical measure of 30 digital pelvic models reconstructed from CT, an anatomic plate was designed according to the complicated structure of the outer table of the posterior ilium, and was integrated into the complete fixation system. Then, an ad hoc semi-automatic mesh generator was employed to construct a patient-specific finite element model of whole pelvis, including elaborate sacroiliac joints, important pelvic ligaments, and interpubic disc, as well as position-dependent cortical thickness and trabecular bone elastic modulus. Following, one side of sacroiliac joint related ligaments were deleted to simulate a complete unilateral sacroiliac joint disruption. Then the new anatomic fixation system was integrated to fix the fracture, and two comparing models including iliosacral screw fixation and front reconstruction plate fixation were also generated. Finally, all models were simulated under same loading conditions. The results demonstrated that the mechanical stability of the new anatomic fixation system was superior, with obviously improved stress distribution and little displacement, which implied an effective internal fixation method for potential clinical application.

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Extending the A-Patch Single Sheet Conditions to Enable the Tessellation of Algebraics

A-patches are a form of representation of an algebraic curve or surface over a simplex (a triangle for a curve, a tetrahedron for a surface). Essentially, the algebraic is represented in Bernstein form, and if its Bernstein coefficients meet certain conditions, then it is in A-patch format. One advantage of A-patches is that the conditions guarantee that a single sheet of the curve/surface passes through the simplex, which provides for straightforward tessellation of the algebraic over the simplex. We can also test the Bernstein representation of the algebraic to see if the algebraic passes through the simplex. If it does and it is in A-patch format in the simplex, we can tessellate it. If the algebraic passes through a simplex but its Bernstein representation is not in A-patch format, then we can subdivide the simplex and repeat the process. This gives an adaptive subdivision style marching tetrahedra algorithm whose advantage is that it guarantees that we do not miss features of the algebraic: singularities are localized, and in regions around nearby multiple sheets, the subdivision process continues until the sheets are separated. Unfortunately, the A-patch single sheet conditions are too strict: for some algebraics, the subdivision process converges slowly or fails to converge. In this paper, I give an additional single sheet condition for curves that allows for convergence of this process. I also give additional conditions for surfaces that trades off some of the single sheet guarantees for improved convergence.

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NURBS Based Molecular Force Calculation

The progress of nanotechnology has made it possible to make miniature electromechanical devices of submicrometer scale. This means that we will be in need of design packages that can model the physical properties of objects and their interactions involved down in nanometer scale. Toward this goal, our aim in this paper is to develop a computing procedure for determining molecular interaction forces, i.e. van der Waals force, between objects of arbitrary geometry. Currently there are two types of approaches for calculating van der Waals force. The first type is analytical where analytical force equations are derived for interactions between simple geometries such as spheres and half-spaces. The second type is numerical where volume integrals or surface integrals are conducted over discretized object domains where the object boundaries are approximated by simple mesh geometries. This paper presents a numerical approach that uses non-uniform rational B-spline (NURBS) based surface integrals. The integrals are done on the parametric domains of the NURBS surfaces and Gaussian quadrature points lie exactly on the object surfaces. Salient features of this approach include: 1) Orders of magnitude in accuracy improvement is achieved over other numerical approaches; The fundamental reason for such accuracy improvement is that molecular interaction force is very sensitive to surface geometry since it falls off at the rate of inverse power of 6 7. Any geometric approximation in object discretization would lead to significant bias in the calculation result. 2) Molecular interactions between arbitrary-shaped objects can be represented and evaluated since the NURBS model can represent exactly common analytical geometries such as spheres in nano-particles and cylinders in nano-rods, and complex geometries such as corrugated sample surfaces. We demonstrate its general shape applicability by calculating van der Waals force between complex geometries such as micro-gears. Further, we give error bounds for NURBS based numerical simulation and develop an adaptive subdivision scheme to improve both calculation accuracy and efficiency.

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Multi-Core Collision Detection Between Deformable Models

We present a new parallel algorithm for interactive and continuous collision detection between deformable models. Our algorithm performs incremental hierarchical computations between successive frames and parallelizes the computation among multiple cores on current CPUs. The main computations include front building and updating and performing the elementary tests between the triangle primitives. The overall algorithm can perform inter- and intra-object collisions at interactive rates on current commodity processors on models with many tens of thousands of triangles. In practice, the performance of our algorithm almost scales linearly with the number of cores.

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Compression of Geometric Data

The paper will address new levels of compression of information that has applications for storage and transmission of geometric data for various uses, including physical modeling. New developments in statistical communication theory have compression ratios that exceed known levels of Martin-Lof randomness in random sequential strings. This has applications to storage and transmission of information in the form of geometric data. Theory and application will be presented in this paper.

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