IP0

Pierre Bezier Award Lecture - On Geometric Interoperability

Interoperability of CAD systems has been sought after since the earliest design systems came to be used. But translating shape representations, and models, faces substantial difficulties that originate in part from mathematical facts. Moreover, shape translation also runs counter to the business models of the software houses. The talk will discuss approaches to geometric interoperability that have the potential to overcome many of these obstacles and to deliver practical interoperability that side-steps the traditional problems associated with model translation and standardization. This is joint work with Vadim Shapiro (Wisconsin) and Vijay Srinivasan (NIST).

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IP1

Human-Centered CAD System

Consumers increasingly demand products that are easy to use and cause the minimum fatigue on the user side or provide the maximum effect while in use. These types of design activity that consider the effect on the human body in the course of design are referred to as human-centered design. An integrated framework that allows a simultaneous modeling of a product and a human user, simulation of both product and human behavior, and modification of the product based upon the simulation results is described. Case studies using the proposed approach are also illustrated.

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IP2

Isogeometric Analysis: Progress and Perspectives

Computational geometry has until recently had little impact upon the numerical solution of partial differential equations. The purpose of this talk is to explore Isogeometric Analysis, in which NURBS (Non-Uniform Rational B-Splines) and T-Splines are employed to construct exact geometric models of complex domains. I will review recent progress toward developing integrated Computer Aided Design (CAD)/Finite Element Analysis (FEA) procedures that do not involve traditional mesh generation and geometry clean-up steps, that is, the CAD file is directly utilized as the analysis input file. I will summarize some of the mathematical developments within Isogeometric Analysis that confirm the superior accuracy and robustness of spline-based approximations compared with traditional FEA, and I will summarize the requirements that methods of computational geometry must satisfy to be suitable for FEA.

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IP3

Generalized Barycentric Coordinates

In 1827 August Ferdinand Mbius published his seminal work on the "barycentric calcul" which provided a novel approach to analytic geometry. One key element in his work is the idea of barycentric coordinates which allow to write any point inside a triangle as a unique convex combination of the triangle's vertices. Only recently, this idea has been extended to polygons with more than three vertices and arbitrary polytopes in higher dimensions, yielding an efficient method for interpolating data given at the vertices of an arbitrary polytope. We discuss the theoretical background of these generalized barycentric coordinates and present several useful applications, e.g. in computer graphics, computer aided geometric design, and image processing.

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IP4

Spectral Properties of Discrete Surface Energies

Beyond the Laplacian and its associated Dirichlet energy exist several other differential operators and energies on surfaces. The spectra encode useful information, often characterizing local and global geometric topological features of a surface, many of them beyond classical curvature properties. The spectral analysis of surfaces has many open problems, most famous the reconstruction of a surface from its spectrum. In the talk we design a new family of energies and operators on discrete surface meshes, and study their usefulness for applications including fast interactive surface modeling, derivation of surface signatures and mesh filtering.

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IP5

Nearest Neighbor Searching in Metric Spaces, and Related Concepts

Metric spaces are very simple geometric structures: they comprise a set and a distance measure that obeys the triangle inequality. Nearest neighbor searching is a fundamental algorithmic problem that can be posed and solved in the general setting of metric spaces, in particular when the (intrinsic) dimension of the space is small. A variety of geometric constructions, such as building meshes and graded triangulations, can be usefully understood as finding a "well distributed" set in a metric space with an appropriate distance measure. I will lightly survey such algorithms and constructions.

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IP6

Computational Geometry and Topology Meet Geometric Modeling

In recent years several techniques primarily developed in the area of computational geometry and topology have been applied to various geometric modeling problems. As a result robust methods for various geometric modeling problems have been developed along with theoretical guarantees. In this talk we consider the problems of curve and surface reconstruction, mesh generation, and feature identification to illustrate how mathematics from geometry and topology interacts with algorithms to provide such certified computational tools. We explain the theoretical results, delineate the algorithms, and present experimental results.

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CP0

Inference-Based Procedural Modeling of Solids

As virtual environments become larger and more complex, there is an increasing need for more automated construction algorithms to support the development process. We present an approach for modeling solids by combining prior examples with a simple sketch. Our algorithm uses an inference-based approach to incrementally fit patches together in a consistent fashion to define the boundary of an object. This algorithm samples and extracts surface patches from input models, and develops a Petri net structure that describes the relationship between patches along an imposed parameterization. Then, given a new parameterized line or curve, we use the Petri net to logically fit patches together in a manner consistent with the input model. This allows us to easily construct objects of varying sizes and configurations using arbitrary articulation, repetition, and interchanging parts. The result of our process is a solid model representation of the constructed object that can be integrated into a simulation-based environment.

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CP0

Efficient and Good Delaunay Meshes From Random Points

Our Conforming Delaunay Triangulation (CDT) algorithm uses uniform random points, and achieves the same quality as deterministic Delaunay refinement: angles in [30, 120] degrees. Random meshes are preferred for graphics, fracture mechanics, and mesh validation. We mesh 2d nonconvex domains with holes, required points, and multiple regions in contact. Point-generation takes O(n) memory and E(n log n) time; triangulation is O(n) for both. Given points located in a square background grid, each point is meshed independently in constant time, using radial sorting. Our CPU and GPU implementations scale well. CPU speed matches Triangle's, our GPU is 2x faster.

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CP0

Geometric Characteristics of Conics in Bezier Form

In this paper we address the calculation of elements of conic sections (axes, asymptotes, centres, eccentricity, foci...) given in Bezier form in terms of their control polygons and weights, making use of real and complex projective and affine geometry.

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CP0

Extended Grassfire Transform on Medial Axes of 2D Shapes

We present a global shape measure on the medial axis of a 2D shape and a definition of a center point. We reveal a number of properties of the shape measure and center point that resemble those of the boundary distance function and the medial axis, and show that they can be generated using a firefront propagation similar to Blum's grassfire analogy. The shape measure and center point are compared with existing formulations, and demonstrated in several applications including pruning medial axes, aligning shapes, and shape matching.

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CP0

Triangular Bubble Spline Surfaces

We present a new method for generating a G^n-surface from a triangular mesh of compatible surface strips, which is a network of polynomial curves with an associated implicitly defined surface. Our method is based on a new type of surface patches, called bubble patches, to represent the individual surfaces. The construction of a single patch is simple, independent of the neighboring patches and works uniformly for triangular meshes with vertices of arbitrary valency. The resulting surface is a piecewise rational surface, which interpolates the given network of polynomial curves.

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CP0

Gpu-Accelerated Hausdorff Distance Computation Between Dynamic Deformable Nurbs Surfaces

We present a parallel GPU-accelerated algorithm for computing the Hausdorff distance from one NURBS surface to another, within a bound. We make use of axis-aligned bounding-box hierarchies that bound the NURBS surfaces to accelerate the computations. We dynamically construct as well as traverse the bounding-box hierarchies for the NURBS surfaces using operations that are optimized for the GPU. To compute the Hausdorff distance, we traverse this hierarchy after culling bounding-box pairs that do not contribute to the Hausdorff distance. Our contribution includes two-sided culling tests that can be performed in parallel using the GPU. The culling, based on the minimum and maximum distance ranges between the bounding boxes, eliminates bounding-box pairs from both surfaces that do not contribute to the Hausdorff distance simultaneously. We calculate accuracy bounds for our computed Hausdorff distance based on the curvature of the surfaces. Our algorithm runs in real-time with very small guaranteed error bounds for complex NURBS surfaces. Since we dynamically construct our bounding-box hierarchy, our algorithm can be used to interactively compute the Hausdorff distance for models made of dynamic deformable surfaces.

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CP0

An Iterative Algorithm for Homology Computation on Simplicial Shapes

In this paper, we propose a new iterative algorithm for computing the homology of arbitrary shapes, discretized through simplicial complexes. Here, we demonstrate how the simplicial homology of a shape can be effectively expressed in terms of the homology of its sub-components. The proposed algorithm retrieves the complete homological information including the Betti numbers, the torsion coefficients and the representative homology generators. To the best of our knowledge, it is the first algorithm based on the *constructive* Mayer-Vietoris sequence, which relates the homology of a topological space to the homologies of its sub-spaces, i.e. the sub-components of the input shape, and their intersection. We demonstrate the validity of our approach with a particular shape decomposition, based only on topological properties, which minimizes the size of the intersections between the sub-components and increases the efficiency of the algorithm.

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CP0

Isogeometric Analysis and Shape Optimization Via Boundary Integral

In this paper, we present a boundary integral based approach to isogeometric analysis and shape optimization. It uses the same basis, Non-Uniform Rational B-Spline (NURBS) basis, for both geometry representation and boundary integral based analysis. Boundary points corresponding to Greville abscissae are used as collocation points. We conducted h-, p- and k-refinement study and shape optimization for linear elasticity problems. Our study finds that 1) the NURBS based boundary integral method is computationally efficient, 2) it bypasses the need for domain parameterization, a bottleneck in current NURBS based volumetric isogeometric analysis; 3) it enables tighter integration of CAD and analysis.

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CP0

Estimating Effects of Removing Negative Features on Engineering Analysis

This paper provides a general framework for the quantitative estimation of the effects of removing negative features on engineering analysis, or *modification sensitivity* for short. There are two main applications: (i) when defeaturing models so that finite element analysis may be carried out more quickly and with lower memory requirements, and (ii) when performing iterative design based on finite element analysis. Our approach can handle large as well as small features, and features with Neumann/natural boundary conditions prescribed on them; previous methods have difficulties in handling such cases. Estimation of the modification sensitivity is achieved by reformulating it as a modeling error caused by use of different mathematical models to describe the same engineering analysis problem. Results are obtained using the dual weighted residual (DWR) method in combination with a heuristic assumption of small variation of dual solution after defeaturing. The final derived sensitivity estimator is expressed in terms of the difference of local boundary integrations over the feature boundary, which can be explicitly evaluated using solutions defined on the defeatured model. The algorithm's performance is demonstrated using a Poisson equation. Comparisons to results obtained by previous approaches indicate it is both accurate and computationally

efficient.

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CP0

Fast and Robust Generation of City-Scale Seamless 3D Urban Models

Since the introduction of the concept of "Digital Earth," almost every major international city has been reconstructed in the virtual world. A large volume of geometric models describing urban objects has become freely available in the public domain via software like ArcGlobe and Google Earth. Although mostly created for visualization, these urban models can benefit many applications beyond visualization including city scale evacuation planning and earth phenomenon simulations. However, these models are mostly loosely structured and implicitly defined and require tedious manual preparation that usually takes weeks if not months before they can be used. Designing algorithms that can robustly and efficiently handle unstructured urban models at the city scale becomes a main technical challenge. In this paper, we present a framework that generates seamless 3D architectural models from 2D ground plans with elevation and height information. These overlapping ground plans are commonly used in the current GIS software such as ESRI ArcGIS and urban model synthesis methods to depict various components of buildings. Due to measurement and manual errors, these ground plans usually contain small, sharp, and various (nearly) degenerate artifacts. In this paper, we show both theoretically and empirically that our framework is efficient and numerically stable. Based on our review of the related work, we believe this is the first work that attempts to automatically create 3D architectural meshes for simulation at the city level. With the goal of providing greater benefit beyond visualization from this large volume of urban models, our initial results are encouraging.

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CP0

Positive Gordon-Wixom Coordinates

We introduce a new construction of transfinite barycentric coordinates for arbitrary closed sets in 2D. Our method extends weighted Gordon-Wixom interpolation to non-convex shapes and produces coordinates that are positive everywhere in the interior of the domain and that are smooth for shapes with smooth boundaries. We achieve these properties by using the distance to lines tangent to the boundary curve to define a weight function that is positive and smooth. We derive closed-form expressions for arbitrary polygons in 2D and compare the basis functions of our coordinates with several other types of barycentric coordinates.

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CP0

Computing the Medial Axis of 3D Regions Bounded by B-Spline Surfaces

A new approach is presented for computing the interior 3D medial axis of regions bounded by parametric B-spline surfaces. In the generic situation, the 3D medial axis consists of smooth surfaces along with a singular set consisting of edge curves, branch curves, fin points and six junction points. The medial axis singular set is first computed using a collection of robust higher order techniques. Medial axis surfaces are computed as a time trace of the evolving self-intersection set of the boundary under the the eikonal (grassfire) flow. The proposed algorithm presents a complete solution along with accurate topological structure.

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CP0

C^2 Splines Covering Polar Configurations

A polar configuration is a triangle fan in a quad-dominant mesh; it allows for many mesh lines to join at a single polar vertex. This paper shows how a single tensor-product spline of degree $(3, 6)$ can cap a polar configuration with a C^2 surface. By design, this C^2 polar spline joins C^2 with surrounding bi-3 tensor-product splines and thereby complements algorithms that smoothly cap star-like, multi-sided regions.

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CP0

A Hybrid Parallel Solver for Systems of Multivariate Polynomials Using CPUs and GPUs

In this paper, we present a hybrid parallel algorithm for solving systems of multivariate constraints by exploiting both the CPU and the GPU multicore architectures. We dedicate the CPU for the traversal of the subdivision tree and the GPU for the multivariate polynomial subdivision. By decomposing the constraint solving technique into two different components, hierarchy traversal and polynomial subdivision, each of which is more suitable to CPUs and GPUs, respectively, our solver can fully exploit the availability of hybrid, multicore architectures of CPUs and GPUs. Furthermore, our GPU-based subdivision method takes advantage of the inherent parallelism in the multivariate polynomial subdivision.

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CP0
Modeling with Rational Biquadratic Splines

We develop a rational bi-quadratic G^1 analogue of the non-uniform polynomial C^1 B-spline paradigm. The G^1 splines can exactly reproduce parts of multiple basic shapes, such as cyclides and quadrics, and combine them into one smoothly-connected structure.

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CP0
Blends of Canal Surfaces from Polyhedral Medial Transform Representations

We present a new method for constructing G1 blending surfaces between an arbitrary number of canal surfaces. The topological relation of the canal surfaces is specified via a convex polyhedron and the design technique is based on a generalization of the medial surface transform. The resulting blend surface consists of trimmed envelopes of one- and two-parameter families of spheres. Blending the medial surface transform instead of the surface itself is shown to be a powerful and elegant approach for blend surface generation. The performance of our approach is demonstrated by several examples.

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CP0
Inspired Quadrangulation

This paper presents a new approach for the quadrangulation of triangular surfaces. We introduce a new example-based quad-meshing paradigm, in order to easily reproduce the subjective decisions made in the design of reference examples found in a corpus. The algorithm enables to reproduce the subjective aspects of the example (extraordinary vertex layout) while minimizing the induced distortion; allowing users to leverage reference meshes considered of quality for fast prototyping. Our technique supports localized mesh composition and enables to reproduce meshing styles despite intrinsic reflective symmetry, large variation from isometry or even topological variation.

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CP0
Transfinite Surface Interpolation over Irregular N-Sided Domains

Transfinite surface interpolation is a classic topic of CAGD and many non-quadrilateral schemes are known. Surfaces defined solely by means of their boundary curves and cross-tangent functions are needed, for examples, in 3D curve-network based design and to fill complex irregular holes such as with vertex blends. This paper deals with interpolating so-called tangential ribbons. Former schemes are enhanced and extended in order to minimize shape artifacts and to provide a more natural patch interior. The proposed representation is based on irregular convex domains that correspond to the lengths and orientations of the boundary curves. The mapping of the individual ribbons within the n-sided domain are calculated by a special line-sweep method that assures a balanced orientation related to the center of the domain, and avoids parametric shearing. Distance-based blending functions ensure that modifying or inserting a small edge will have only a local effect over the n-sided patch. The construction supports the generation of one- or two-sided patches, as well. Examples and open research topics conclude the paper.

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CP0

Non-Uniform Recursive Doo-Sabin Surfaces

This paper presents a generalization of Catmull-Clark-variant Doo-Sabin surfaces and non-uniform biquadratic B-spline surfaces called NURDSes (Non-Uniform Recursive Doo-Sabin Surfaces). One step of NURDS refinement can be factored into one non-uniform linear subdivision step plus one dual step. Compared to the prior non-uniform Doo-Sabin surfaces (i.e., quadratic NURSSes), NURDSes are convergent for arbitrary n-sided faces. Closed form limit point rules, which are important for applications in adaptive rendering and NC machining, are given as well.

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CP0

Adaptive Isogeometric Analysis Using Rational Pht-Splines

Both NURBS-based IGA and T-splines-based IGA show great advantageous compared to FEA with respect to the convergence of the analysis and accuracy of the results, but suffer from the drawback of a purely local refinements. In this paper, we extend PHT-splines to Rational form, and explore Rational PHT-splines as the basis for analysis. A residual-based posteriori error estimator is derived to guide a local h-refinements process adaptively. The numerical results show that RPHT-splines are most promising as basis for IGA and the given posteriori error estimator and the refinement strategy are efficient and reliable.

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CP0

Efficiently Computing Geodesic Offsets on Triangle Meshes by Extended Xin-Wang Algorithm

Geodesic offset curves are important for many industrial applications, such as solid modeling, robot-path planning, the generation of tool paths for NC machine, etc. Although it is well studied in classical differential geometry and computer-aided design, where the underlying surface is sufficiently smooth, very few algorithms are available for computing geodesic offsets on discrete representation, in which the input is typically a polyline curve restricted on the piecewise linear mesh. In this paper, we propose an efficient and exact algorithm to compute the geodesic offsets on triangle meshes by extending the Xin-Wang algorithm of discrete geodesics. We define new data structure for parallel-source windows, and extend both the "one angle one split' and the filtering theorem to maintain the windows tree. Similar to the original Xin-Wang algorithm, our extended algorithm has an $O(n)$ space complexity and an $O(n^2 \log n)$ asymptotic time complexity, where n is the number of vertices on the input mesh. We tested our algorithm on numerous real-world models and showed that our algorithm is efficient and insensitive to the mesh resolution/tessellation.

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CP0

Computing Shortest Words Via Shortest Loops on Hyperbolic Surfaces

Computing the shortest homotopy representations for loops on general surfaces is an NP-hard problem. However, for surfaces allowing hyperbolic metrics and equipped with canonical homotopic generators, this problem can be reduced to finding homotopic shortest loops. In this paper, we propose an efficient solution to compute the shortest words on triangulated surfaces of this special case. The framework uses hyperbolic metrics and transient embedding to compute shortest paths and shortest loops, which gives rise to a solution of the shortest words problem. Several techniques are employed to relieve numerical errors. Experimental results are given to demonstrate the performance in practice.

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CP1

Cubic Helical Splines with Frenet-Frame Continuity

We present a scheme of interpolating a sequence of points in space by a piecewise-cubic-helical spline with continuous Frenet frame. Each cubic helical segment connecting adjacent data points is constructed such that its end tangents are symmetric with respect to the displacement vector of the data points. The existence condition of such a segment is formulated in terms of the configuration involving the displacement vector and the Frenet frame of the segment at the initial point. A Frenet-frame-continuous spline is obtained by matching the Frenet frames of sequentially constructed segments at their juncture points.

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CP1

Quaternionic Bezier Curves and Surfaces

Quaternionic Bezier (QB) curves and surfaces in 3-space are defined by Bezier-like formulas with quaternionic weights. Any rational Bezier curves and surfaces on 2-spheres can be converted into QB-form of twice lower degree (e.g., a circular arc is a linear QB-curve). Using implicitization formula for general bilinear QB-surfaces it is shown that they are patches on quartic surfaces called Darboux cyclides. In particular principal patches of Dupin cyclides can be parametrized by special bilinear QB-surfaces.

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CP1

Linear Methods for Degree Reduction with Geometric Continuity

Degree reduction of Bézier curves and surfaces facilitates data exchange, compression, transfer, and comparison. Existing methods for degree reduction with geometric continuity constraints at the end points are non-linear. In this talk, we present linear methods for degree reduction with geometric continuity constraints at the end points.

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CP1

Singularity of Cubic Bézier Curves and Surfaces

Parametric cubic polynomial curves and surfaces are useful in applications, being of relatively low dimension, and yet, flexible in their shape. To use these curves and surfaces fully, one must understand the cases of singularity. A parametric curve is singular where its derivative is zero, and a parametric surface, where its normal vector is zero. These singularities are described in terms of the Bézier form of a parametric polynomial curve and surface.

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CP1

Rational Pythagorean-Hodograph Space Curves

A method for constructing rational Pythagorean-hodograph (PH) curves in Euclidean space is proposed, based on prescribing a field of rational unit tangent vectors. This tangent field, together with its first derivative, defines the orientation of the curve osculating planes. Augmenting this orientation information with a rational support function, that specifies the distance of each osculating plane from the origin, then completely defines a one-parameter family of osculating planes, whose envelope is a developable ruled surface. The rational PH space curve is identified as the edge of regression (or cuspidal edge) of this developable surface. Such curves have rational parametric speed, and also rational adapted frames that satisfy the same conditions as polynomial PH curves in order to be rotation-minimizing with respect to the tangent. The key properties of such rational PH space curves are derived and illustrated by examples, and simple algorithms for their practical construction by geometric Hermite interpolation are also proposed.

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CP1

Some Characteristics of Log-Aesthetic Planar Curves

Log-aesthetic planar curves are spiral curves that are the generalization of the Clothoid, Nielsen's spiral, and the logarithmic spiral by shape parameter α. We investigate some characteristics of log-aesthetic curves, such as their evolutes, and the theoretical boundaries of the drawable regions of log-aesthetic curves. We first provide a proof that the evolutes of log-aesthetic curves are also log-aesthetic curves. We then provide a method for drawing a curve segment with the theoretical boundary when $\alpha < 0$ or $\alpha > 1$.

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CP2
Advances in Online Reconstruction with Laser-Scanners

The operator of an hand-held laser-scanner for reverse engineering needs to scan enough details for CAD reconstruction. We improved our online triangulation method that supports the operator in this task. For CAD reconstruction it is not necessary to scan the whole object. Parameters of regular geometry can be determined from a much smaller set of point data. We are currently working on an online CAD reconstruction that segments the point data and fits regular geometry.

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CP2
Surface Mesh Extrusion on the GPU

This presentation explores the details of surface mesh extrusion accelerated using GPU computing through NVIDIA's CUDA technology. Topics include choosing GPU-friendly mesh data structures, optimizing GPU kernel execution, and detecting mesh self-intersection on the GPU.

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CP2
Designing Multiscale Kernels on Meshes

The recent realization that a multiscale kernel, namely the heat kernel, allows extracting information about shapes at multiple levels was found useful in applications such as distance measurement, segmentation, shape matching and retrieval. To increase the scope of applications and to provide a greater assortment of choices, there is a need for new multiscale kernels. In this talk we introduce a general principle for constructing multiscale kernels on surface meshes, and present a construction of the multiscale pre-biharmonic and multiscale biharmonic kernels. The resulting kernels have gradually changing supports, consistent behavior over partial and complete meshes, and interesting limiting behaviors (e.g. in the limit of large scales, the multiscale biharmonic kernel converges to the Green's function of the biharmonic equation); in addition, these kernels are based on intrinsic quantities and so are insensitive to isometric deformations. We show empirically that our kernels are shape-aware, robust to noise, tessellation, and partial object, and are fast to compute. Finally, we demonstrate that the new kernels are useful for function interpolation and shape correspondence.

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CP2
Interactive Surface Modeling Using Modal Analysis

We propose a framework for deformation-based surface modeling that is interactive, robust and intuitive to use. The deformations are described by a non-linear optimization problem that models static states of elastic shapes under external forces which implement the user input. Interactive response is achieved by a combination of model reduction, a robust energy approximation, and an efficient quasi-Newton solver. Motivated by the observation that a typical modeling session requires only a fraction of the full shape space of the underlying model, we use second and third derivatives of a deformation energy to construct a low-dimensional shape space that forms the feasible set for the optimization. Based on mesh coarsening, we propose an energy approximation scheme with adjustable approximation quality. The quasi-Newton solver guarantees superlinear convergence without the need of costly Hessian evaluations during modeling.

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CP2
Noise-Resistant, Feature-Preserving, High-Order Surface Reconstruction for Surface Meshes

We consider the problem of reconstructing a high-order surface from a given surface mesh. We introduce two methods, called Weighted Averaging of Local Fittings (WALF) and Continuous Moving Frames (CMF), both based on weighted least squares polynomial fittings and guarantee C^0 continuity. Our methods are applicable to surface meshes composed of triangles and/or quadrilaterals, can achieve third- and even higher order accuracy, and have integrated treatments for sharp features.

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CP2
Sharp Feature Preserving Mls Surface Reconstruction Based on Local Neighborhood Modifications

Most point sampled geometries from manufactured and designed objects contain sharp features. A standard MLS fitting produces smooth surfaces, but also smoothes sharp features.
To preserve those features, we modify the local neighborhoods the MLS fitting is applied to. In a first step, sharp

feature points are marked in the point set. Then, the selected feature points are used to modify the local neighborhoods only in the presence of sharp features. MLS is applied afterwards.

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CP3

Iso-Geometric Flow Simulations Using Catmull-Clark Finite Elements

We present a novel technique to solve the incompressible steady-state Navier-Stokes equations for flow simulations. The proposed method is an iso-geometric approach based on Catmull-Clark subdivision solids to integrate design and the analysis phase for volumetric models of arbitrary topology. This allows us to use the same representation for the modeling, the physical simulation, and the visualization, which optimizes the development process and narrows the gap between design and simulation. The underlying geometric models are Catmull-Clark surfaces with optional corners and creases. Hence, these models can be simply refined to increase the accuracy of the simulation. The crucial point in the simulation phase is the ability to perform parameter evaluation at any location during the simulation at arbitrary parameter values. We propose a method similar to the standard subdivision surface evaluation technique, such that numerical quadrature can be used. The non-linear system of equations which arises during the simulation is solved by Newton's method. Experiments show that our approach approximately requires the same number of iterations as linear Lagrangian hexahedral finite elements for the same number of degrees of freedom. As Catmull-Clark finite elements are tri-cubic we can achieve higher accuracy with the same number of degrees of freedom and almost the same computational cost. Increasingly, it is computationally desirable to closely couple geometry design, alteration and representation with the actual simulation operating on the geometry. Iso-geometric design and modeling is an evolving area that is aiming to address the issues related to the close coupling and integration of geometry and simulation, and our methods presented provide a novel approach in support of this trend.

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CP3

Subdivision-Based Modeling for Isogeometric Analysis

The main concept of isogeometric analysis is to directly use basis functions of the computer aided design (CAD) geometry for representing solutions of the physical space. This talk presents some ongoing work on isogeometric analysis using subdivision-based representations. The general methodology is first discussed. Different modelling options are briefly highlighted. Key issues in using subdivision-based modelling for isogeometric analysis are further addressed. Some open problems will also be discussed.

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CP3

Parallel Particle Tracking Implementation on GPUs for Unstructured Grids

Particle tracking methods are often used to model groundwater contaminant transport since they provide solutions free of numerical dispersion. Typical applications involve domains that are irregularly discretized. Unstructured meshes use fewer nodes, but require additional computation in a parallel setting, whereas brute-force techniques using highly refined structured meshes are easily parallelized. A particle tracking algorithm designed to run in parallel on GPUs is presented. Scenarios with structured and unstructured meshes are discussed in detail.

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CP3

Regularity and Approximation Properties for Singular Parameterizations in Isogeometric Analysis

Isogeometric Analysis is a numerical method which uses the NURBS-based representation of CAD-models. Singularly parameterized surfaces are used to represent non-quadrangular domains without splitting. In the presence of singularities the test functions do not necessarily fulfill the required regularity and approximation properties. Considering two types of singularities, we derive conditions which guarantee the regularity of the test functions and show approximation properties of the function spaces. We suggest a parameterization strategy depending on the considered problem.

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CP3

Implicitized Distance Fields for Computationally Efficient Point Containment Checks in Isogeometric Models

In recent research, we developed a hierarchical compositional philosophy mirroring constructive solid geometry [D. Natekar, X. Zhang, and G. Subbarayan. "Constructive Solid Analysis: A Hierarchical, Geometry based Meshless Procedure for Integrated Design and Analysis." *Computer Aided Design*, vol. 36, pp. 473-486, 2004; M. Rayasam, V. Srinivasan, G. Subbarayan, "CAD inspired hierarchical partition of unity constructions for NURBS-based, meshless design, analysis and optimization," *International Journal for Numerical Methods in Engineering*, vol. 72, pp. 14521489, 2007] for isogeometric analysis by composing *(using function space formalism)* functional approximations for the geometry and its associated behavioral field. In compositional procedures, point-containment checks identify relative contribution of each primitive to the overall approximation, but are expensive to calculate at each integration point. Here, we describe an algebraic, implicitized procedure to carryout point containment checks inexpensively without surface intersection calculations.

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CP4

Efficient Computation of Electrostatic Interactions in Bio-Molecules in the Generalized Born Model Via the R6 Effective Radii

Constructing physically realistic and computationally effective representation of the molecular surface remains challenging. We illustrate some of the challenges and describe a solution in the context of the generalized Born model, a popular analytical approximation for computing electrostatic interactions in biomolecules. The proposed solution is based on the $|r|^{-6}$ integral over an approximation to the molecular volume. Overall, the solution offers a reasonable balance between efficiency and accuracy, especially if applied to small drug-like molecules.

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CP4

A Semi-Implicit Method of Mean Curvature Flow

We propose a new semi-implicit method for mean-curvature flow using a triangulated surface. For spatial discretization, our method computes curvatures using a weighted least-squares approximation. To address the stiffness of the differential equation, we propose a semi-implicit method that enhances the stability and allows for a substantial enlargement of the time step. We present experimental comparisons with other methods to demonstrate the accuracy and stability of our proposed method.

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CP4

Equilibrium Shapes of Two-Component Vesicles under Spontaneous Curvature

The modeling of biological structures, known as vesicles, is based on the minimization of its membrane energy (or shape energy). Most of the current vesicle models assume that bending energy is the dominating factor in determining vesicle shape. Our study analyzes vesicle shape based on a different source, known as spontaneous curvature. Through numerical simulation, we show that the presence of spontaneous curvature leads to many shapes that are both interesting and, we believe, experimentally relevant.

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CP4

DeWaLoP Robot - Dynamical Independent Suspension System

This work describes the geometrical design of the Dynamical Independent Suspension System (DISS) for the Developing Water Loss Prevention DeWaLoP in-pipe robot, which objective is to redevelop the pipe-joint of fresh water supply system of Vienna and Bratislava. The DISS enables the wheeled-legs from the robot system to expand, creating a rigid structure inside the pipe, so the redevelopment tools work; or to compress, becoming a mobile platform able to move inside the pipelines.

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CP4

Configurations of Closed Diblock Fibers

We analyze the conformations of closed diblock fibers which consist of two blocks with different bending rigidities and spontaneous curvatures. In each fiber, one block is a bare polymer while the other is an adsorbed protein-filament complex. The length fraction of each component and the total fiber length is controlled by tunable chemical potentials. We analytically calculate the shape of these two-component polymers for all values of the material parameters and chemical potentials. Our results yield: a complete analytical description of all possible two-component polymer conformations in two and three dimensions, a phase portrait detailing the parameter spaces in which these shapes occur, and the identification of spontaneous transitions between shapes driven by environmental changes.

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CP4

Finite Element Approximation in Shape Optimization Problems with Neumann Or Mixed Boundary Conditions

For optimal design problems, defined in domains of class C and in arbitrary space dimension, governed by elliptic equations with boundary conditions of Neumann or mixed type, we introduce the corresponding discretized problems and we prove convergence results. The discretization method is of fixed domain type, in the sense that it is given in the domain that contains all the admissible open sets.

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CP5

Using Implicit Equations of Parametric Curves and Surfaces Without Computing Them: Polynomial Algebra by Values

In many geometric problems involving algebraic curves and surfaces, such as the point position problem, the equations to be solved involve polynomials of huge size, which are extremely difficult to work with. We show that, taking as input a set of values of the considered polynomials, the solution of the equations can be reduced to generalized eigenvalue problems on matrix pencils, with big, but structured and sparse numerical matrices.

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CP5

Complete Path Planning in the Plane

We present a complete path planning algorithm for a plane robot with three degrees of freedom and a static obstacle. The part boundaries consist of linear and circular edges. The algorithm constructs and searches a combinatorial representation of the robot free space. Its complexity is $O((n^4 + c_3)\log n)$ with n the input size and c_3 the number of configurations with three simultaneous contacts between robot and obstacle edges. The algorithm is implemented robustly using our controlled linear perturbation strategy. The program handles passages whose clearance is 10^{-9}. The running time is independent of the clearance.

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CP6

Concave and Alpha Hulls of a Set of Freeform Planar Closed Curves

Given a set of points, what is the region occupied by them? Convex hull, concave hull, α-hull, poly hull, r-shape and s-shape have been proposed. In this paper, we extend the question to a set of close planar freeform curves (represented as NURBS) without sampling them. We propose concave hull by defining it and also present an algorithm. Also the relation between α-hull (extended from point-sets) and concave hulls is explored.

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CP6

Medial Zones As 'Thick' Skeletons

We formally define the new concept of a *medial zone* of an n-dimensional semi-analytic domain Ω that subsumes the medial axis $\mathcal{MA}(\Omega)$ of the same domain as a special case, and can be thought of as a 'thick' skeleton having the same dimension as that of Ω. We will review several of their appealing topological and computational properties and discuss a paradigm to construct them for 3D semi-analytic domains. Due to the fact that the medial zones fuse some of the critical geometric and topological properties of both the domain itself and of its medial axis, reformulating problems in terms of medial zones affords the 'best of both worlds' in applications such as robotic and autonomous navigation, and design automation.

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CP6

Estimating Penetration Depth of Convex Polyghe-

dra Using Dynamic Minkowski Sum

In this talk we will present our recent results on estimating the penetration depth of two overlapping convex polyhedra. In the heart of our approach is a method that can efficiently *update* the Minkowski sums of the convex polyhedra without re-computing every Minkowski sum from scratch. We show that this new penetration depth estimation method provides theoretical guarantee to find a global minimum and is efficient, in particular when the rotation is small between frames.

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CP6
3D Constructive Ma Generation

Medial axis (MA) is a simplified representation of a model. A novel constructive approach for the MA generation of 3D models is proposed based on double queue algorithm (DQA). This approach can generate MA of both a single model and a resultant model constructed from modifying MAs of two operand models via a Boolean operation instead of regenerating the MA from scratch.

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CP7
Smoothness Analysis of Triangular Subdivision Algorithms

A C^1 analysis technique for infinite classes of subdivision schemes for arbitrary quadrilateral meshes has been developed by the authors and the class of subdivision schemes which includes simplest and midpoint schemes and all their possible combinations has been analyzed. In this talk, we discuss some issues in applying this technique to triangular subdivision algorithms. In particular, a new infinite class of triangular schemes is defined, and we analyze the smoothness of their subdivision surfaces.

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CP7
Parameterizing Subdivision Surfaces

We present a method for parameterizing subdivision surfaces in an as-rigid-as-possible fashion. While much work has concentrated on parameterizing polygon meshes, little work has focused on subdivision surfaces despite their popularity. We show that polygon parameterization methods produce suboptimal results when applied to subdivision surfaces and describe how these methods may be modified to operate on subdivision surfaces. We also describe a method for creating extended charts to further reduce the distortion of the parameterization.

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CP7
Recent Advances in NURBS-Compatible Subdivision

While subdivision based on uniform B-splines is very well understood now, non-uniform bivariate schemes still pose some challenges. In regular regions, one can rely on univariate results and use tensor products. However, in extraordinary regions, the situation is much more complex. A real breakthrough came only recently with the thesis of Thomas Cashman and resulted in NURBS-compatible subdivision. Although this framework has answered many questions, it cannot handle even-degree schemes and multiple knots in extraordinary regions. Solutions to some of these shortcomings will be presented in the talk.

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CP7
Error in Multivariate Polynomial Interpolation

Using polynomials to interpolate bivariate data has mixed results: sometimes the interpolating surfaces are good but other times the interpolating surfaces fluctuate wildly. In this talk, we look at the error term of the interpolant, noting that any fixed basis will produce poor results for some data sets, and we explain why schemes such as the Least usually produce good interpolants.

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CP7

G^1 Bzier Surface Interpolation of Boundary Curves with T-junction

A T-junction is the junction point of two boundary curves, where one boundary curve starts in the middle of another boundary curve. We propose the piecewise G^1 Bzier surface interpolation method from the boundary curves with T-junction in which none of the boundary curves are changed. The key idea of this research is that two micro surfaces that are subdivided by the T-junction can be considered one macro surface. This yields a G^1 continuity problem between two macro patches. With this condition, we add the vertex G^1 condition between two micro patches related with the T-junction. A T-junction can occur also at a 3-valent vertex. Two of three boundary curves that are collinear at a vertex, also define a T-junction. We give a necessary condition to interpolate G^1 Bzier surfaces and suggest a subdivision method with three rectangular sub-patches at this type of T-junction. In this research, we solve the vertex G^1 continuity constraints and edge G^1 continuity constraints independently and we propose constraints using scalar weight functions for making consistent linear systems of the vertex and edge G^1 systems. We show the shaded models and the reflection lines, and check the angles of the resulting surfaces to verify the G^1 continuity.

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CP7

A Herarchical Approach for Generalised B-Splines

One promising alternative to classical tensor-product splines is given by Hierachical B-splines recently discussed in Jüttler et al. (2011). In this approach B-spline basis functions have been considered as the main ‘building block”. In this talk we shall present a first study about the possibility to extend the Hierachical approach to Generalized B-splines which have been recently used as an alternative to NURBS in IgA.

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CP8

Biharmonic Volumetric Mapping Using Fundamental Solutions

We propose a biharmonic volumetric mapping framework based on fundamental solutions. Unlike the traditional harmonic map that only allows boundary positional conditions with C^0 continuity, biharmonic mapping allows users to flexibly control boundary constraints on both positions and normal derivatives and obtain C^1 transition along boundary interfaces. This facilitates the parameterization of huge or inhomogeneous volumetric models whose mapping can be more effectively computed by a divide-and-conquer strategy with the help of model decomposition.

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CP8

Volume Parameterization Using Sequences of Harmonic Maps

Volume parameterization has attracted significant research efforts recently due to the emergence of isogeometric analysis which requires a structural mesh as an input for numerical analysis. We present a 2-step method for constructing a regular parameterization of a simply connected domain. We first build an injective mapping from the domain to the parameter domain by using a sequence of harmonic maps. Then we parameterize the original domain by spline approximation of the inverse mapping.

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CP8

Dynamical System Modelling of Cyanobactria’s Circadian Rhythm

We consider about cyanobactria’s Circadian rhythm by use of its characteristic dynamics. We investigate it from the deterministic and stochastic point of view to make some important properties of cyanobactria’s Circadian rhythm be comprehensible mathematically.

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CP8

Adaptive Grid Generation Using the Composition of Tensor Product B-Splines

We describe an adaptive grid generation technique based on the composition of tensor product B-spline mappings, $\mathbf{T}^* = \mathbf{T} \circ \mathbf{\Phi}$, where $\mathbf{\Phi}$ maps the unit square onto itself and $\mathbf{T}$ maps the square onto the desired physical domain. Technique allows us to reparameterize grid boundary curves without disturbing the accuracy of the spline boundary approximation. Application to interactive visualizations in the NIST Digital Library of Mathematical Functions (http://dlmf.nist.gov) will be shown.

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CP8

Contouring Discrete Indicator Functions

We present a method for calculating the boundary of objects from Discrete Indicator Functions. Although Marching Cubes is effective at calculating contours of functions sampled over discrete grids, it performs poorly when contouring non-smooth functions and generates surfaces exhibiting aliasing and oscillations. We derive a simple vertex placement method that removes these artifacts, is efficient, easy to implement, and does not require any optimization or iteration.

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CP8

Automating Spline Tessellation

This talk presents tight geometric and parametric bounds that ensure that splines are rendered without artifacts in the standard graphics pipeline. An implementation on the GPU shows little overhead.

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MS1

Challenges for CAD Systems

This presentation will address some of the issues the CAD industry is currently facing, for example the problem of capturing design process knowledge in parametric models in a usable form.

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MS1

Challenges in Isogeometric Analysis (IGA)

IGA replaces traditional Finite Elements by watertight structures of 3-variate NURBS. The introduction of NURBS in FEA allows accurate representation of CAD-shapes in FEA. However, efficient technology for establishing watertight IGA-models from CAD-models has to be developed, local refinement of IGA-models has to be improved, and direct GPU-based visualization of IGA-models has to be developed. IGA potentially simplifies analysis of as-is models as the path from measurement through CAD to analysis is shortened.

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MS1

Towards a New Surface Modeling Capability

Four years ago in the Forward Looking Session in this conference series, several challenge problems were posed by industrial participants. This talk presents recent progress made towards the solution to one of those challenge problems.

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MS1

Challenges in Topology-based Modeling

There is a growing need for computational topology algorithms in many research areas in engineering and life sciences. In this talk we present fundamental techniques and their applications in fiber modeling, urban planning and computational fluid dynamics.

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MS2

Parametrization in Isogeometric Analysis

We discuss ways to extend a parametrization of the boundary of a domain to the interior. This is important in a shape optimization context where the boundary is changed in every optimization cycle. We will in particular study the Winslow functional which turns out to have some desirable properties. Minimizing the Winslow functional is too costly during the optimization. Instead a linearized version can be used and the full Winslow functional is only used when necessary.

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MS2

Optimization and Modeling of 3D Scanner Data

As lasers and other scanners become more accurate and affordable, their use in industry is increasing. This is presenting new challenges in generating surface models from discrete data. Creating these models involves data fusion, statistical analysis, constrained data fitting of noisy data, and more. We will present some applications of 3D scanners around The Boeing Company and then discuss how we frame and solve the associated data fitting problems as problems in constrained optimization.

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MS2

Isogeometric Shape Optimal Design Based on a Novel Class of Conservative Convex Approximations

We present an isogeometric shape optimisation framework with multilevel design considerations and shape regularisation features. A novel class of globally convergent, conservative convex approximations is proposed to formulate and solve the design problems. In addition, formulation of frequently employed geometric constraints is considered. Validity and efficiency of the framework is demonstrated through structural optimisation of thin-walled shells.

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MS2

B-Spline Based Shape and Topology Optimization

In this talk, I present our recent work on the use of B-spline based finite elements in shape and topology optimization. In shape optimization, we show how NURBS weights can be used as design variables and how B-spline mesh can be generated from Coons patches. Shape optimization examples on linear elasticity and band gap in photonic crystals will be demonstrated. In topology optimization, we demonstrate how mesh-dependency and order-dependency in B-splines can be avoided by applying filtering in the Gaussian quadrature points. Topology optimization examples with minimal length control on the optimized structures will be demonstrated.

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MS3

Computational Challenges in Bio-Nano Technology

Bio-nanotechnology has started to come of age. Starting from the early (1959) visionary ideas of physicist Professor Richard Feynman, the nascent field has been propelled by teams of scientists spanning multiple disciplines (biologists, chemists, computer scientists, mathematicians, physicists). There are seemingly daily reports of new discoveries of biological methods for de-nuovo nano-medicine, macromolecular drug delivery mechanisms, DNA computers, nanoscale information storage and retrieval, self-assembly graphene sheets, carbon-nanotubes, and molecular motors, etc. In this talk, however I shall focus on some of the necessary computational and applied mathematics infrastructure and challenges that enable and accelerate scientific discovery in bio-nano technology.

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MS3

New Challenges in Curve and Surface Modeling

For each advance in curve and surface modeling technology, new refinements and capabilities are needed to respond to ever growing challenges in modeling applications. This talk will explore some of the new capabilities currently being sought in response to new demands being placed on geometric models.

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MS3

Computational Impact of Discrete Differential Geometry

Discrete triangle meshes are the raw input data for higher order spline representations. Nevertheless many novel algorithms from discrete differential geometry are designed for such raw data. In our symposium contribution we will discuss the geometry processing pipeline leading from raw data to high quality geometry representations. Especially important is the suitability of various geometry representations for numerical simulations.

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MS3

Challenges in Virtual Tower Operations for Air Traffic Control

The SESAR (Single European Sky Air Traffic Management Research) programme is a large research and development project launched by the European Community. The programme is the technological and operational part of the Single European Sky (SES) initiative to meet future capacity and air safety needs. This talk will describe a small sub-project of this huge effort, namely one dealing with the introduction of novel concepts for 3D modelling of remote (unmanned) tower operations.

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MS4

Analysis Aware Representations, Parameterizations, and Models

Isogeometric Analysis (IA) has been proposed as a methodology for bridging the gap between Computer Aided Design (CAD) and Finite Element Analysis (FEA). In order to support design and full 3D IA, new ab initio design methods must create suitable representations and approximation techniques must include parameterization methodologies for volumes. This presentation discusses some of the challenges in moving from current representations and datafitting techniques towards this goal and demonstrates initial results and analyses.

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MS4
Splines and Isogeometric Analysis (IGA)

The idea behind IGA was to reuse CAD-type NURBS in analysis. CAD hides B-spline basis functions from the user, while direct access to basis functions is essential in analysis. Refinement of B-spline representation was available in 1980 (Oslo-algorithm), local refinement of tensor product B-splines was not important before IGA. IGA has consequently triggered new uses of and increased research into splines, and potentially allows interoperability of design and analysis through new requirements to spline technology.

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MS4
Locally Refined B-splines

We will address local refinement of tensor product B-splines specified as a sequence of inserted line segments parallel to the knot lines. We obtain a quadrilateral grid with T-junctions in the parameter domain, and a collection of tensor product B-splines on this mesh here named an LR-mesh. The approach applies equally well in dimensions higher than two. Moreover, in the two dimensional case this collection of B-splines spans the full spline space on the LR-mesh.

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MS4
Translation of CAD Models to Block Structured Isogeometric Models

A CAD solid is implicitly represented by its bounding surfaces while a model intended for isogeometric analysis need a trivariate representation. Moreover, CAD models are represented by different types of surfaces, not only NURBS, and the surfaces are frequently trimmed, while block structured isogometric models are regular collections of non-trimmed NURBS volumes. It is not trivial to translate an arbitrary CAD model into an isogeometric model. Some CAD solids, however, employ a certain regularity which makes an automatic translation into a model fit for isogeometric analysis feasible. This talk will focus on removal of trimming from CAD surfaces by block structuring and how a block structured face set can be turned into a trivariate model.

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MS5
Comparing Solid Representations of Protein Cavities to Reveal Influences on Protein-Ligand Binding Specificity

This talk presents VASP, a new method that dissects biochemically active cavities in protein structures to isolate structural elements that influence binding specificity. VASP enables these new capabilities by exploiting a novel representation of protein structures based on Computational Solid Geometry and Boolean set operations. Applying VASP to an analysis of the major serine proteases, VASP isolated individual amino acids and regions of functional sites that enable the serine proteases to preferentially bind specific molecules.

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MS5
Molecular Surfaces for Poisson-Boltzmann Electrostatics

The Poisson-Boltzmann equation provides a model for the electrostatic interaction of a protein with an implicit solvent. The resulting energy computations depend on the interface between the protein and the solvent, the molecular surface. There are several molecular surface constructions each designed for a different goal: preservation of idealized geometry, smoothness, ease of computation, etc. We compare molecular surfaces based on their impact on the solvation energy for a practical set of proteins.

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MS5
The Geometry of Biomolecular Solvation: Hydrophobicity and Electrostatics

Biomolecules adopt stable 3D structures and perform their functions in water. Modeling the water-biomolecule interactions, namely, solvation, is essential for understanding the folding, stability and activity of proteins. In implicit solvent model, the water effects are largely determined by the geometry of the molecular-water interface. We use the skin surface to model the surface of biomolecules and develop new approaches for computing the contribution of hydrophobicity and electrostatics to form an effective solvation potential.

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MS5

Evolution Based Skeletonization of 3D Images for Secondary Structure Elucidation in 3D Cryo EM Density Maps

Skeletonization has been widely used as one compact way to represent shape in many fields. This has led to a number of computational techniques for computing skeletons. We propose an evolution based skeletonization method for 3D images which utilizes both geometric and volumetric representations of the object. Important topological information is preserved during the evolution. We apply this approach to elucidating the secondary structures from 3D cryo EM density map of intermediate resolution. Comparison with several other elucidating approaches will be presented.

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MS6

Variational Space Deformation with Barycentric Coordinates

An important problem in Computer Graphics is shape deformation: given a source shape and user defined constraints, the goal is to generate a deformed shape which fulfills the constraints and preserves the local details of the original shape. We show how complex-valued barycentric coordinates provide a natural solution to this problem in two-dimensions, and discuss the modifications required for 3D deformation, and deformation transfer.

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MS6

Geometric Criteria for Generalized Barycentric Finite Elements

Generalized barycentric coordinate functions allow for novel, flexible finite element methods accommodating polygonal element geometries. The Sobolev-norm error estimates associated to such methods, however, require varying levels of geometric criteria on the polygons, depending on the definition of the coordinate functions. In this talk, I will derive these criteria for a variety of coordinate definitions and discuss the practical tradeoffs between enforcing geometric constraints and computing finite element basis functions over polygons.

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MS6

Injective Barycentric Mappings on Convex Domains

Wachspress and mean value coordinates and their extensions to smooth convex domains are generalizations of triangular barycentric coordinates and have recently been used to construct mappings between convex polygons or domains, with applications to curve deformation and image warping. We will show that Wachspress mappings between convex domains are always injective but that mean value mappings can fail to be so in extreme cases. Possible extensions of our results to convex polyhedra will also be discussed.

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MS6

Constructing Barycentric Coordinates on Surfaces

This talk introduces a method for defining and efficiently computing barycentric coordinates with respect to polygons on general surfaces. Our construction is geared towards injective polygons (polygons that can be enclosed in a metric ball of an appropriate size) and is based on replacing the linear precision property of planar coordinates by a requirement in terms of center of mass, and generalizing this requirement to the surface setting. We show that the resulting surface barycentric coordinates can be computed using planar barycentric coordinates with respect to a polygon in the tangent plane. We prove theoretically that the surface coordinates properly generalize the planar coordinates and carry some of their useful properties such as unique reconstruction of a point given its coordinates, uniqueness for triangles, edge linearity, similarity invariance, and smoothness; in addition, these coordinates are insensitive to isometric deformations and can be used to reconstruct isometries. We show empirically that surface coordinates are shape-aware with consistent gross behavior across different surfaces, are well-behaved for different polygon types/locations on variety of surface forms, and that they are fast to compute. Finally, we demonstrate effectiveness of surface coordinates for interpolation, decal mapping, and correspondence refinement.

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MS7

Variational Hexahedral Subdivision of Volumetric Domains

In this talk I shall briefly survey the approach of variational methods in hexahedral mesh quality improvement. I shall then contrast the choice of a few different high-order energy functionals by their Euler-Lagrange equation i.e a non-linear elliptic or biharmonic partial differential equation (PDE), and the discretization formulas of the differential operators. Finally, I shall describe several applications of these methods in producing feature preserving, quality hexahedral parameterizations.

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MS7

Hex-based Representations of Volumes from Midstructures

In this talk we discuss techniques to construct hex-based representations from input tetrahedral meshes. In particular, we present methodologies to decompose a volumetric domain into simpler pieces that employ mid-structures to establish a structured hex-based representation. The decomposition is based on a hybrid parameterization which mixes a polycube-like with a polar-like parameterization to employ each one's advantages. It guarantees that adjacent components have a matching parameterization on shared boundaries. The presented methodologies are based on a midstructure which is constructed for the object in advance. We discuss strategies for constructing midstructures and look at generalizations.

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MS7

Polycube Parameterization for Hexahedral Remeshing

We study the volumetric parameterization on polycube domain and discuss its application on hexahedral remeshing. Uniform hexahedral meshes can be generated on a polycube domain, and by mapping this polycube to a given volumetric shape, we can transfer the regular hex structure from the polycube to the given shape. The main pipeline for such an approach usually contains two steps: (1) constructing the polycube domain (which determines the topological structure and singularities of the hex-mesh), and (2) the volumetric mapping (which affects the angle/volume distortions of the transferred hex-grids and thus the meshing quality). We will introduce and briefly discuss several algorithms of hexahedral remeshing based on polycube parameterization.

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MS7

Hexahedral Parameterization

We discuss novel techniques to fill a bounded volumetric shape with a (preferably coarse) cubical voxel structure. Among the optimization goals are alignment of the voxels with the bounding surface as well as simplicity of the voxel grid. Mathematical analysis of the possible singularities is given. The algorithm is uses a tetrahedral volume mesh plus a user given guiding frame field as input. Then it constructs an atlas of chart functions, i.e. the parameterization function of the volume, such that the images of the coordinate lines align with the given frame field. Formally the function is given by a first-order PDE, namely the gradients of the coordinate functions are the vectors of the frame. In a first step, the algorithm uses a discrete Hodge decomposition to assure local integrability of the frame field. A subsequent step assures global integrability along generators of the first homology group and alignment a face of the boundary cube with the original surface boundary. All steps can be merged into solving linear equations. Conceptually the presented CubeCover-algorithm extends the known QuadCover-algorithm from surface meshes to volumes meshes.

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MS8

Improved T-splines

In this talk, I will present a variant version of T-splines. The new spline improves T-splines in the following aspects by consctructing new spline functions. The blending functions: (1) are polynomial instead of rational; (2) are linearly independent; (3) have good properties like B-splines, such as nonnegativity, partition of unity and compact support. Examples are provide the modelling ability of the new splines.

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MS8

Isogeometric Simulation of Turbine Blades

Isogeometric analysis is a novel approach to numerical simulation that has the potential to bridge the gap between geometric design and numerical analysis. It uses the same exact geometry representation in all stages of the product development. It is particularly promising to apply IGA to functional free-form surfaces, where small changes of the geometry can lead to major changes in the performance. The talk reports recent results obtained for the isogeometric simulation of turbine blades.

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MS8

Efficient Algorithms for Freeform Geometric Models

We present a new approach to the development of efficient geometric algorithms for freeform curves and surfaces. Preprocessing the given freeform geometric models and representing them in a hierarchical data structure, we show that a variety of geometric algorithms can be greatly accelerated. We demonstrate the effectiveness of this approach by developing a real-time dynamic simulation of freeform geometric models that is based on efficient algorithms for collision detection and minimum distance computation.

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MS8
Robust Modeling of Minimal Surfaces

Centroidal Voronoi tessellation (CVT) is an optimal Voronoi diagram such that each generator coincides with the centroid of its Voronoi cell. The CVT has widely been used for data visualization and mesh generation but seldom for shape modeling. In this talk we show how the CVT can be applied to modeling discrete minimal surfaces with a given boundary. The variational formulation of the problem and efficient optimization algorithms are presented. The proposed approach generates triangle meshes approximating minimal surfaces with better distributed mesh vertices than previous methods. The extension to computing constant mean curvature surfaces will also be discussed.

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MS9
Harmonic Analysis Meets Stochastic Geometry

In the field of Stochastic (or Integral) Geometry, the Principal Kinematic Formula describes in closed form the volume in the group of rigid-body motions corresponding to when two convex bodies are in collision. But obtaining exact results for nonconvex bodies has been elusive for the past century. In this talk, lower and upper bounds are derived in this case using concepts of convolution and Fourier analysis on the group of rigid-body motions. Applications in automated assembly planning will be discussed.

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MS9
Lie Group Morphology with Convolutions

There are at least three applications of Minkowski sums in geometric modeling: sweeping, configuration-space-obstacles, and computation of workspaces . Group morphology generalizes these applications to non-commutative transformations, such as rotations or affinities, by making a careful distinction between transformations and the objects on which they act. We show that binary group morphology can be understood in terms of representation theory and convolutions, which leads to new efficient and practical algorithms for all types of Minkowski operations.

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MS9
Uniform Deterministic Sampling of Rotation Groups from Successive Orthogonal Images

The ability to construct uniform deterministic samples of rotation groups is useful in many contexts, such as molecular docking and medical imaging, but there are inherent mathematical difficulties that prevent an exact solution. The talk will present successive orthogonal images, an effective means for uniform deterministic sampling of orthogonal groups. The method is valid in any dimension, and analytical bounds are provided on the sampling uniformity. Numerical comparisons with other sampling methods are given for the special case of $SO(3)$. We make use of non-Riemannian distance metrics that are group-invariant and locally compatible with the Haar measure. In addition, our results provide a semi-unique decomposition of any orthogonal matrix into the product of planar rotations.

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MS9
Steady Affine Motions: Interpolation, Properties, Applications

The morph between a shape S and a shape E may be decomposed into a shape deformation and a carrier motion. Most shape deformations either assume or compute their a correspondence. Minkowski morphs compute correspondence based on surface orientation. Closest projection morphs compute correspondence based on distance. The ball morph takes both distance and orientation into account. Other approaches use curvature or saliency to compute correspondence. The focus on this presentation is on the carrier motion. We propose to use a Steady Affine Morph (SAM), which we compute as A^t, where A is the affinity that minimizes the discrepancy between A(S) and E. We present the beautiful properties of SAMs and their computation. We invite a discussion on the relation between the particular morph used, the particular correspondence, the discrepancy measure, and the goodness measure for the resulting morph.

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MS10
Delaunay-based Meshes

Delaunay meshes are versatile structures for partitioning domains with complex geometry into simple elements. They also come with practical and efficient construction algorithms that offer mathematical guarantees on the element quality. We will highlight the results on generating Delaunay meshes for polyhedral volumes and surfaces. A domain may change its shape with time. We will outline our progress on tracking a Delaunay-based mesh for a deforming surface specified by dense point samples.

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MS10

Optimal Homology Cycles and Knots

On a simplicial complex, can one efficiently find the smallest homology cycles (as measured by number or size)? In mod 2 homology, the problem is NP-hard in general. However, for integer coefficients, if the complex satisfies a certain topological condition (being relatively torsion-free) then optimal homology cycles can be found in polynomial time in any dimension. The algorithm is simply linear programming. Being relatively torsion-free is equivalent to a well-known condition in linear programming that guarantees integer solutions. This result is then applied to solve a problem that was open in computational knot theory: for knots embedded in trivial homology manifolds, such as in ordinary three-dimensional space, the minimal spanning area problem can be solved in polynomial time. The result on optimal homology cycles is joint work with T. Dey and B. Krishnamoorthy. The knots result is joint work with N. Dunfield.

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MS10

Robust Computation of Delaunay Triangulations by Degree Driven Algorithm Design

Algorithms are designed for machine models that have three potentially unbounded quantities: running time, memory cells, and bits per cell. Designers optimize the first two, but often don't consider the third. This can create. in geometry processing, a large effort gap between a theoretically correct algorithm and a robust implementation. Liotta, Preparata and Tamassia suggested that the third could also be considered a resource by limiting the algebraic degree of predicates. We use this idea in the design and implementation of Delaunay triangulation algorithms.

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MS10

Spectral Processing Based on Laplace-Beltrami Operator

The Laplace-Beltrami operator of a given manifold (e.g, a surface) is a fundamental object encoding the intrinsic geometry of the underlying manifold. It has many properties useful for practical applications from areas such as graphics and machine learning. For example, its relation to the heat diffusion makes it a primary tool for surface smoothing in graphics. It has recently been used for a broad range of graphics and geometric optimization applications, such as mesh editing, compression, matching, segmentation, and etc. In this talk, I will first describe our recent results on approximating the Laplace operator for general mesh or point clouds by a geometric approach. I will then talk about several applications based on the Laplace-Beltrami operator, including information estimation, shape matching, and shape deformation.

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MS11

Space-efficient Maintenance of Nonbonded Lists for Flexible Molecules using Dynamic Octrees

The most time consuming calculations in molecular simulations are associated with nonbonded interactions, such as van der Waals and electrostatic energy functions. The truncation of nonbonded interactions based on distance cutoffs is widely used to reduce the high computational costs of such interactions, which is traditionally handled through the use of a precalculated and periodically updated explicit list of interacting atom pairs, known as the "nonbonded list" or nblist. The size of an nblist grows linearly with the number of atoms in the system (say, n), and cubically with the distance cutoff (say, d). We propose a dynamic octree data structure that can be used for implicit maintenance of nblists using space linear in n but independent of d, and can be updated very efficiently as the shape of the molecule changes. Dynamic octrees are more space-efficient, update-efficient and cache-efficient compared to traditional explicit nblists. Also unlike explicit nblists a single octree can be used for all distance cutoffs. Though octrees are slightly slower than explicit nblists when the distance cutoff is small, they outperform nblists for large cutoffs.

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MS11

Signatures and Basis Set of Protein Binding Surfaces: Surface Matching in Sequence Order Independent Fashion for Function Prediction

Three dimensional structures of proteins and their dynamic changes are the basis of their biological functions. Detecting similarities between local binding surfaces can facilitate identification of binding sites, prediction of protein functions, as well as aid in our understanding of biochemical mechanisms. Local binding sites often take place in a concave surface pocket. Using Delaunay triangulation of the three-dimensional protein structure and the alpha complex, we compute all surface pockets and other local concave regions on a protein. We discuss how new insights into protein function can be gained by reconstructing the evolutionary history of binding pockets, and how to predict protein functions from structures at large scale by finding structurally invariable regions within the binding pocket. To address the challenging task of automatically constructing a template of local surface characteristics of a specific biological function or binding activity, we discuss the model of signature binding pockets and signature basis sets, as well as a computational method called Solar (Signature Of Local Active Regions) for their automatic constructions. We discuss how automatically constructed signatures and signature basis sets of functional pockets can reveal significant biological insight. In addition, we assess the feasibility of deriving signatures of binding pockets through the aid of the bootstraps of comparatively modeled structures. Our results using 26,590 modeled protein structures show that when the sequence fragments of the binding surface share sufficient similarity, informative signature binding pockets can be derived, with most important atoms in the signatures of binding pockets captured.

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MS11
Analytical Electrostatics: Methods and Biological Applications

Electrostatic forces are the strongest interactions at molecular level, and one of the hardest to compute for complex biomolecular shapes. I will begin with a brief overview of the benefits, successes and challenges in developing methods that provide *analytical* approximate description of charge-charge interactions in biomolecular systems, as opposed to direct numerical solutions. Construction and biophysical applications of approximate analytical solutions to the Poisson equation for boundary conditions relevant to biomolecules will be discussed. I will conclude by presenting my view on the current challenges in the field, including the need for a new generation of physically realistic mathematical descriptions of biomolecular shape.

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MS11
Visualizing and Exploring Molecular Simulation Data via Topological Methods

Current computation power enables researchers to produce a huge amount of folding simulation data. Hence there is a pressing need to be able to analyze such data to enhance our understanding of molecular dynamics. Such simulation data can be considered as a massive set of high dimensional points, with each point representing a protein conformation. Each conformation also has an energy associated with it. In this talk, we will describe our recent work on using a topological method based on the contour trees to construct a visualization platform for such simulation data, as well as how to use this tool for data analysis.

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MS12
On the Numerical Analysis of Some T-splines Based Isogeometric Methods

This talk will be about some new results on the mathematical foundations of Isogeometric analysis. We will focus on the use of T-splines as a refinement tool and we will illustrate the main steps which are needed to develop the numerical analysis of T-splines based methods.

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MS12
On the Normalization of Hierarchical B-splines

The hierarchical model allows us to control the locality of the refinement through an adaptive procedure that is exclusively based on basis refinement. It can be suitably modified in order to define locally supported basis functions that form a partition of unity. Reducing the support of basis functions defined on coarse grids, in accordance with finer levels in the hierarchy, not only decreases the overlapping of basis supports, but it also improves stability properties.

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MS12
Analysis-suitable Local Refinement of T-splines

Isogeometric analysis has emerged as an important alternative to traditional engineering design and analysis methodologies. In isogeometric analysis, the smooth geometric basis is used as the basis for analysis. T-splines were introduced as a superior alternative to NURBS. T-splines can model complicated designs as a single, watertight geometry. Unlike NURBS, T-splines can be locally refined. These properties make T-splines an ideal technology for isogeometric discretizations. In this talk, we will briefly review T-spline technology and then we will discuss analysis-suitable local refinement. We will describe the underlying algorithm and demonstrate its behavior in the context of a demanding phase-field fracture model.

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MS12

On the Use of Powell-Sabin B-splines for Local Refinement in Advection-diffusion-reaction Problems

Powell-Sabin splines are C^1 quadratic splines defined on triangulations. They can be represented in a basis with the same nice properties of the classical B-spline basis. We discuss the use of these splines for the numerical solution of advection-diffusion-reaction problems. They constitute a natural bridge between classical FEM and the NURBS-based Isogeometric Analysis. They offer the flexibility of FEM with respect to local refinements and share the increased smoothness with NURBS.

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PP1

Modeling Wing Surfaces During Collision Avoidance Behaviors of Flying Locusts

Collision avoidance is critical in evading predation, especially during flight. We presented looming stimuli (simulated colliding objects) to locusts (Schistocerca americana) while the subjects were flying under a variety of tether configurations in a wind tunnel. Stereoscopic high-speed video was used to record their behavior as they sought to avoid a collision. The collected video data was then used to reconstruct the flight trajectory, body direction, and wing beat patterns and deformations as the subject undertook collision avoidance responses.

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PP1

A Predictive Model for Geographic Statistical Data

Any planar map may be transformed into a graph. If we consider each country to be represented by a vertex (or node), if they are adjacent they will be joined by an edge. To consider how trends migrate across boundaries, we obtain relevant measures of the statistic we want to consider; namely, the index of prevalence, and the index of incidence. We define a cycle by a given unit of time, usually a year. We then propose various alternate equations whereby, by parametrizing various variables, such as population size, birth rate, death rate, and rate of immigration/emigration, we calculate a new index of prevalence/index of incidence, for the next cycle. For a given data set, each statistic we consider may propagate by a different equation, and/or a different set of parameters; this will be determined empirically. What we are proposing is, technically, to model how a discrete stochastic process propagates geographically, according to geographical proximity. Very often, statistics that depend on geographical proximity are tabulated by variables that are not; i.e., alphabetically. Such a predictive model would be relevant in areas such as public health; and/or crime mapping, for law enforcement purposes. We present an application using a GIS (geographic information system).

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PP1

High Accuracy NC Milling Simulation Using Distance Fields of Swept Volumes

We introduce a new 3D shape representation called a Composite Adaptively Sampled Distance Field and describe its applications to swept volumes. In the case of NC milling simulation, the distance fields represent both the workpiece and the swept volumes generated by the 3-axis or 5-axis motion of the milling tool along its prescribed path. The resulting representation enables reconstruction of the milled surface with micron accuracy while having modest memory requirements for large and complex shapes. The system provides significant improvements over previous approaches to milling simulation.

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PP1

3D-Cad Data for Massive Assembly Models Considering Feature of Production Facility Models

Using 3D-CAD systems for production facilities has a problem to process massive number of parts. We take notice of the shapes of parts on production facility models: most of them are united and subtracted projections, revolutions, and simple holes at right angles, and we propose the new

data structure with small data size, specialized for the production facility models. This enables us to process up to 400,000 parts on our 3D-CAD system.

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PP1

Hybrid Geometric Modeling for Orthopedic Surgery Planning

Surgery planning for internal fractures involves aligning bone fragments (reduction), and deforming fixation plates to fit patient anatomy (adaptation). We propose a hybrid-geometry based planning system with standard plate CAD models and polygonal bone data as input. A novel feature of the system is the creation of NURBS-based models of patient-specific plates semi-automatically that can then be produced with CNC machines. The system improves planning accuracy, reduces burden on surgeons and ultimately improves patients outcome.

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PP1

Shape Optimization of Sub-Wavelength Antennas Using Isogeometric Analysis

We aim to design an antenna that concentrates the magnetic energy from an incoming electromagnetic wave in a very small region of space. This relates to the problem of wireless energy transfer. We use shape optimization and isogeometric analysis to attack the problem. Even though we only consider the problem in 2D the results are very promising. Compared to earlier attempts using topology optimization we increase the energy in the designated area with factor of one million.

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PP1

Regularization in Isogeometric Shape Optimization for Fluids

The goal in shape optimization for fluids is to find an optimal boundary of the flow domain that minimizes a prescribed objective, while satisfying suitable constraints. Inclusion of an artificial objective term is often needed to avoid inappropriate boundary parametrizations and thereby regularize the optimization problem. This work uses isogeometric analysis as framework for the numerical method and discusses various regularizations by comparing their effects in different examples.

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PP1

Applied Computational Homology Toward Structural Study to Protein Science

In protein science, one of important problems is that structural property of each protein should be determined. We adopt homology group (Rips homology, or) to calculate the number of ”holes” and ”cavities” in each protein. This is very important information about the structure of the protein.

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PP1

Multiresolution Methods in Isogeometric Analysis

In this research we implement subdivision schemes and wavelets for isogeometric finite element analysis. The subdivision schemes are routinely employed in computer graphics and animation and their applications in finite element modeling has recently started. The application of wavelets in numerical solution of PDEs has been so far limited to simple geometries. We outline application of wavelet based multiresolutional methods in modeling arbitrary topology via use of subdivision schemes.

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PP1

High-Order Numerical Integration over Discrete Surfaces

We investigate the problem of numerical integration over a discrete surface to high-order accuracy. Presently, integration over discrete surfaces (such as a surface triangulation) is in general limited to only second-order accuracy. We present a novel method that can achieve high order accuracy, by combining a stabilized least squares approximation for high-order surface and functional reconstructions, a blending procedure, and high order numerical quadrature rules.

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PP1

Simple Determination of Geometric Characteristics of Bézier Conics

We show how to compute in a straightforward manner the geometric characteristics of a conic segment in rational Bézier form, by employing complex arithmetic. For a central conic, a simple quadratic equation defines the foci location, and its solution furnishes not only an explicit formula for the foci, but also for the centre, axis direction and linear eccentricity. Other characteristics, such as axis lengths or eccentricity, result from traditional geometry.

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