Report from Dagstuhl Seminar 14221

Geometric Modeling

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 14221 "Geometric Modeling". This is the 9th Dagstuhl seminar on "Geometric Modeling", and the seminar was attended by 44 leading researchers coming from 3 continents and 20 countries. A total of 45 presentations were grouped together into 12 lecture sessions and 3 perspective working group sessions. There was also ample time for stimulating and fruitful person to person and group discussions in the harmonic Dagstuhl atmosphere.

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1 Executive Summary

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The 9th Dagstuhl seminar was attended by 44 leading researchers coming from 3 continents and 20 countries. A total of 45 presentations were grouped together into 12 lecture sessions and 3 perspective working group sessions. There was also ample time for stimulating and fruitful person to person and group discussions in the harmonic Dagstuhl atmosphere. Dagstuhl seminars on Geometric Modelling are among the most interdisciplinary events within Geometric Modelling. The reason is the seminar format and the generous numbers of targeted invitation to leading researchers across the different research communities addressing Geometric Modelling. Geometric Modeling is the branch of Computer Science concerned with the acquisition, representation, modeling and analysis of 3-dimensional and higher dimensional geometry. The evolution of IT-technology with Cloud Computing and the big data challenge, and novel manufacturing technologies such as 3D printing and layered manufacturing, as well as the introduction of Isogeometric Analysis drive a need for increased innovation within Geometric Modeling. The Dagstuhl seminars on Geometric Modelling are one of the main driving forces facilitating such innovation.

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The twelve lecture sessions covered a wide range of topics:

- Geometric modelling, analysis and computations;
- Methods in approximate algebraic geometry and implicitization;
- Mesh processing both related to triangulations and isogeometric analysis;
- Optimization and Isogeometric Analysis;
- Splines over triangulations an and locally refinable splines;
- Material modelling and reverse engineering;
- Funding opportunities for Geometric Modelling within Horizon 2020.

The three perspective working groups have each written a short document reporting on approach and result of the session. The perspective working group on subdivision addressed the state of the art and the future research challenges of subdivisions. The group on 3D printing approached the challenges from the current wide media coverage of 3D printing and challenges experienced by industry using 3D printing. The group on modeling of material microstructures was approaching the topic from additive manufacturing, and the challenges faced by the geometric modelling community to support modeling and representation of such material structures in variety of applications. As with all previous Dagstuhl Seminars on Geometric Modeling, the conference proceedings will be published, the 2014 proceedings as a special issue of the Elsevier Journal Graphical Models. A special event during the conference was the John Gregory Memorial Award honoring Elaine Cohen, Jörg Peters and Ulrich Reif. This award is presented every three years at Dagstuhl and honors fundamental contributions to the field of geometric modeling. The organizers thank all the attendees for their contributions and extend special thanks to the team of Schloss Dagstuhl for helping to make this seminar a success. As always, we enjoyed the warm atmosphere of the Schloss, which supports both formal presentations as well as informal exchanges of ideas.

2 Table of Contents

3 Overview of Talks

3.1 Numerical methods for implicitization

Oliver Barrowclough (SINTEF IKT Applied Mathematics – Oslo, NO)

Main reference O. J. D. Barrowclough, "Numerical methods for implicitization and their applications," in T. Dokken and G. Muntingh, eds., SAGA – Advances in Shapes, Geometry, and Algebra – Geometry and Computing, Vol. 10, Springer, 2014; to appear.

A long standing problem in computer aided geometric design has been the robustness of intersection algorithms. Geometries resulting from intersections often lack watertightness and have incorrect topology, requiring costly repair procedures to be applied prior to analysis or manufacturing. One technique that can support the robustness and consistency of geometric computations is implicitization. In this talk we present some recent approaches to computing implicitizations numerically. This includes both exact methods for low degree curves, and approximate methods, which are better suited to higher degree surfaces and envelopes.

3.2 Biharmonic fields and mesh completion

Pere Brunet (UPC – Barcelona, ES)

We discuss biharmonic fields which approximate signed distance fields. We conclude that biharmonic field approximation can be a powerful tool for mesh completion in general and complex cases. We present an adaptive, multigrid algorithm to extrapolate signed distance fields. By defining a volume mask in a closed region bounding the area that must be repaired, the algorithm computes a signed distance field in well-defined regions and uses it as an over-determined boundary condition constraint for the biharmonic field computation in the complementary regions. We discuss this approximation in practical examples in the case of raw triangular meshes resulting from laser scan acquisitions which require massive hole repair. We conclude that the proposed algorithm is robust and general, being able to deal with complex topological cases.

3.3 Properties of Matrix Representations of Rational Bézier Curves and Surfaces

Laurent Busé (INRIA Sophia Antipolis – Méditerranée, FR)

Main reference L. Busé, "Implicit matrix representations of rational Bézier curves and surfaces," Computer Aided Design, Vol. 46, pp. 14–24, 2014; pre-print available at HAL.
URL http://dx.doi.org/10.1016/j.cad.2013.08.014
URL http://hal.inria.fr/hal-00847802

Matrix-based implicit representations of rational Bézier curves and surfaces in the 3-dimensional space have been extensively developed during the last fifteen years by many authors. They have a lot of interesting properties, so that they can be considered as representations on their own. One of their well-known advantage is that they adapt geometric problems, such as intersection problems, to the powerful tools of numerical linear algebra, as the singular value decomposition.

In this talk, we will focus on the behavior of these matrix representations with respect to numerical computations. We will also show that a distance-like function can be defined from a matrix representation.

3.4 Some Problems on Splines over T-meshes

Falai Chen (University of Science & Technology of China – Anhui, CN)

Joint work of Chen, Falai; Deng Jiansong; Li, Xin
Main reference J. Deng, F. Chen, X. Li, C. Hu, W. Tong, Z. Yang, Y. Feng, "Polynomial splines over hierarchical T-meshes," Graphical Models, 74(4):76–86. 2008.
URL http://dx.doi.org/10.1016/j.gmod.2008.03.001

In this talk, I will summarize some recent advances on splines over T-meshes, including dimension calculation, basis construction and applications in geometric modeling and isogeometric analysis. I will then put forward some further research problems.

3.5 Direct Isosurface Visualization for Hex-based High Order Geometry and Attributes

Elaine Cohen (University of Utah, US)

With the increasing use of hexahedral based high order trivariate representations, there is increasing need for accurate visualization methods for both the geometry and any related attributes and simulation results. This talk discusses one such approach.

3.6 Challenges from IsoGeometric Analysis to CAGD–Experiences from the TERRIFIC project

Tor Dokken (SINTEF IKT Applied Mathematics – Oslo, NO)

Main reference T. Dokken, T. Lyche, K. F. Pettersen, "Polynomial splines over locally refined box-partitions," Computer Aided Geometric Design, 30(3):331–356, 2013.
URL http://dx.doi.org/10.1016/j.cagd.2012.12.005
URL http://www.terrific-project.eu

The TERRIFIC-project (funded under EUs Factories of the Future program, 2011-2014) ends in August 2014, www.terrific-project.eu. TERRIFIC aims at significant improvement of the interoperability of computational tools for the design, analysis and optimization of functional products. An isogeometric approach is applied for selected manufacturing application areas (cars, trains, aircraft) and for computer-aided machining. The talk illustrated the achievements of TERRIFIC illustrated by the TERRIFIC demonstrator part, and addressed the many open challenges still remaining to be solved before IsoGeometric Analysis can be deployed to industry on a broad scale.

3.7 Precise Continuous Contact Motion Analysis for Freeform Geometry

Gershon Elber (Technion – Haifa, IL)

Joint work of Gershon Elber; Yongjoon Kim; Myung Soo Kim; Michael Baron; Helmut Pottmann

This work presents an efficient algorithm for generating a continuous and precise contact motion between geometric models bounded by piecewise polynomial C^1-continuous parametric B-spline curves and surfaces.

The contact configurations are characterized algebraically. We will start by discussing simpler cases of curves' contact in the plane, only to continue and considered a CNC tool (cylinder)-freeform surface contact in multi-axis machining context. Hyper osculating circles are considered along with double tangency contacts, in the case of tool-surface analysis.

We strive to ensure the topology of the reconstructed solution and we demonstrate the effectiveness of the proposed approach using several examples of both 2D curve-curve contacts and 3D tool-surface contacts in 5-axis machining scenarios.

3.8 Sparse Approximate Implicitization

Ioannis Z. Emiris (National Kapodistrian University of Athens, GR)

Main reference I. Z. Emiris, T. Kalinka, C. Konaxis, T. Luu Ba, "Sparse implicitization by interpolation: Characterizing non-exactness, and an application to computing discriminants," Computer-Aided Design – Special Issue on Solid and Physical Modeling 2012, 45(2):252–261, 2013.
URL http://dx.doi.org/10.1016/j.cad.2012.10.008

We reduce implicitization of parametric (hyper)surfaces to computing the kernel of a square (or rectangular) numeric matrix. Our algorithm works in the presence of base-points. It relies on predicting the monomial support of the implicit equation by developing tools in sparse elimination theory. In particular, by predicting the Newton polytope of the sparse resultant, we obtain (a superset of) the Newton polytope of the implicit equation, hence all monomials in the implicit equation. This theory allows us to exploit any sparseness in the parametric polynomials as well as in the implicit equation [1]. We can moreover characterize the cases of higher-dimensional kernel [2]: in particular, the predicted implicit polytope is the Minkowski sum of the true implicit polytope and an extraneous polytope; in this case, the implicit equation is the GCD of a number of polynomials.

The method is easy to implement (already developed in Maple), can approximate the exact equation by using a smaller support, and should be generalizable to parameterizations in the Bernstein basis. Certain operations on the surface, such as point membership and sidedness of a query point, can be reduced to matrix operations without computing the implicit equation, namely rank drop and sign of determinant, respectively. Our current work focuses on exploiting the generalized Vandermonde structure of the matrix and on improving numerical stability by controlling point (over)sampling on the surface, e.g. by using Chebyshev points rather than complex roots of unity, which have proven the best choice so far.

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1 I. Z. Emiris, T. Kalinka, C. Konaxis and T. Luu Ba. Implicitization of curves and (hyper)surfaces using predicted support, Theor. Comp. Science, Special Issue on Symbolic-Numerical Algorithms, 479:81–98, 2013.

2 I. Z. Emiris, T. Kalinka, C. Konaxis and T. Luu Ba, Sparse implicitization by interpolation: Characterizing non-exactness, and an application to computing discriminants, J. CAD, Special Issue on Solid and Physical Modeling, 45:252–261, 2013.

3.9 Geometric Variations of the Lane-Riesenfeld Algorithm

Ron Goldman (Rice University, US)

Joint work of Dyn, Nira; Goldman, Ron; Levin, David

The Lane-Riesenfeld algorithm is a classical subdivision procedure for generating uniform B-spline curves and surfaces. Here we discuss some geometric variations of this classical subdivision procedure. Instead of treating each component of a curve or surface independently, we treat the control polygons as geometric entities, where the components do not have independent geometric meanings. The split and averaging paradigm of the Lane-Riesenfeld algorithm is mimicked, but midpoint averaging is replaced by geometric averaging. We discuss what is currently known and not known about the convergence, continuity, and smoothness of such geometric Lane-Riesenfeld algorithms.

3.10 The Geometry of Colour Space

Jens Gravesen (Technical University of Denmark – Lyngby, DK)

The space of colours is a fascinating space. It is a real vector space, but no matter what inner product you put on the space the resulting euclidean distance does not corresponds to human perception of difference between colours.

In applications that involve searching through images it is important to have a good notion of distance between colours. And in the textile industry it is important to be able to determine if residues of old dye have a visible effect on the current colour.

In 1945 MacAdam performed the first experiments on colour matching and found the MacAdam ellipses which are often interpreted as defining the metric tensor (or first fundamental form) at the centres of the ellipses. A fundamental question is whether it is possible to define colour coordinates such that the euclidean distance in these coordinates corresponds to human perception. Put another way, can we find an isometry to euclidean space or what is the curvature of the space colours?

I will report on a simple approach that solves the practical problem but also formulate a purely geometric question of which I only have the answer in the one dimensional case.

References

1 Günter Wyszecki and W. S. Stiles. *Color Science, Concepts and Methods, Quantitative Data and Formulae*. John Wiley and Sons, New York, Chichester, Brisbane, Toronto, Singapore, 2. edition, 1982.

3.11 Efficient computation of NURBS components interfaces

Stefanie Hahmann (INRIA Grenoble Rhône-Alpes, FR)

Joint work of François Jourdes, Georges-Pierre Bonneau, Stefanie Hahmann, Jean-Claude Léon, François Faure
Main reference F. Jourdes, G.-P. Bonneau, S. Hahmann, J.-C. Léon, F. Faure, "Computation of components' interfaces in highly complex assemblies," Computer-Aided Design, 46(Jan. 2014):170–178, 2014; pre-print available at HAL.
URL http://dx.doi.org/10.1016/j.cad.2013.08.029
URL http://hal.inria.fr/hal-00854926

The preparation of CAD models from complex assemblies for simulation purposes is a very time-consuming and tedious process, since many tasks are still completed manually. Herein, the detection and extraction of geometric interfaces between components of the assembly is of central importance not only for the simulation objectives but also for all necessary shape transformations such as idealizations or detail removals. It is a repetitive task in particular when complex assemblies have to be dealt with. This talk presents a method to rapidly and fully automatically generate a precise geometric description of interfaces in generic B-Rep CAD models. The approach combines an efficient GPU ray-casting technique commonly used in computer graphics with a graph-based curve extraction algorithm. Not only is it able to detect a large number of interfaces efficiently, but it also provides an accurate NURBS geometry of the interfaces, that can be stored in a plain STEP file for further downstream treatment. We demonstrate our approach on examples from aeronautics and automotive industry.

3.12 Generalized Lane-Riesenfeld Algorithms

Kai Hormann (University of Lugano, CH)

Joint work of Cashman, Thomas J.; Hormann, Kai; Reif, Ulrich
Main reference T. J. Cashman, K. Hormann, U. Reif, "Generalized Lane-Riesenfeld Algorithms," Computer Aided Geometric Design, 30(4):398–409, 2013.
URL http://dx.doi.org/10.1016/j.cagd.2013.02.001

The Lane-Riesenfeld algorithm for generating uniform B-splines provides a prototype for subdivision algorithms that use a refine and smooth factorization to gain arbitrarily high smoothness through efficient local rules. In this paper we generalize this algorithm by maintaining the key property that the same operator is used to define the refine and each smoothing stage. For the Lane-Riesenfeld algorithm this operator samples a linear polynomial, and therefore the algorithm preserves only linear polynomials in the functional setting, and straight lines in the geometric setting. We present two new families of schemes that extend this set of invariants: one which preserves cubic polynomials, and another which preserves circles. For both generalizations, as for the Lane-Riesenfeld algorithm, a greater number of smoothing stages gives smoother curves, and only local rules are required for an implementation.

3.13 Workshop: The Future Challenges of Subdivision

Kai Hormann (University of Lugano, CH)

In this workshop, we reviewed the state of the art of subdivision methods for geometric modelling and tried to identify the future challenges for this field of research. We agreed that subdivision algorithms for curves are well understood by now, but that we still lack good schemes and analysis tools for surfaces. In particular, we believe that non-linear or geometric surface schemes should be developed and examined, as they have the potential to provide reproduction of basic shapes (cylinder, spheres, etc.) and C^2-continuous and fair limit surfaces.

3.14 TDHB splines: The truncated and decoupled basis of hierarchical spline spaces

Bert Jüttler (University of Linz, AT)

Joint work of Jüttler, Bert; Mokris, Dominik
Main reference D. Mokris, B. Jüttler, "TDHB-splines: The truncated decoupled basis of hierarchical tensor-product splines," Computer Aided Geometric Design, 2014, in press.
URL http://dx.doi.org/10.1016/j.cagd.2014.05.004

We introduce a novel basis for multivariate hierarchical tensor- product spline spaces. Our construction combines the truncation mechanism with the idea of decoupling basis functions. While the first mechanism ensures the partition of unity property, which is essential for geometric modeling applications, the idea of decoupling allows us to obtain a richer set of basis functions than previous hierarchical approaches. Consequently, we can guarantee the completeness property of the novel basis for large classes of multi-level spline spaces. In particular, completeness is obtained for the multi-level spline spaces defined on T-meshes for hierarchical splines of (multi-) degree p (i) with single knots and p-adic refinement and (ii) with knots of multiplicity $m > (p + 1)/3$ and dyadic refinement (where each cell to be refined is subdivided into 2^n cells, with n being the number of variables) without any further restriction on the mesh configuration. Both classes (i,ii) include multivariate quadratic hierarchical tensor-splines with dyadic refinement.

3.15 Bounding Circular Arcs for a Dynamic Bounding Volume Hierarchy

Myung-Soo Kim (Seoul National University, KR)

Joint work of Lee, Jaewook; Kim, Yong-Joon; Elber, Gershon

We consider the construction of dynamic bounding volume hierarchy (BVH) for planar freeform curves under deformation. For this purpose, we employ the Bounding Circular Arcs (BCA), originally proposed by Meek and Walton (JCAM 1995) for the purpose of proving the cubic convergence of their biarc approximation method. The BCA construction is compared with conventional bounding volumes, in particular, with fat arcs and spiral fat arcs. The effectiveness of the BCA-based approach is then demonstrated using a few test examples of geometric computing on planar freeform curves under deformation.

3.16 On the dimension of spline spaces on T-meshes and its applications to the refinement algorithms

Tae-Wan Kim (Seoul National University, KR)

The spline representations using T-mesh as an underlying geometric structure has absorbed substantial interest among designers, engineers and researches for the last decade. One of the fundamental requirements of the refinement technique is being able to generate nested sequence of spline spaces and spline basis functions generating these spline spaces. For example, the construction of hierarchical B-splines or LR B-splines provides feasible algorithms for generating spline basis functions. The dimension of spline space is used to ensure the completeness and linear independence of spline basis functions. In this talk we will discuss about the dimension of spline spaces for some classes of 2-dimensional and 3-dimensional T-meshes. In particular we will demonstrate how the results about the dimension of a spline space can be used to show the completeness of hierarchical B-splines. We will also discuss some alternative refinement techniques that essentially use a formula for the dimension of a spline space.

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1 Dmitry Berdinsky, Tae-wan Kim, Cesare Bracco, Sutipong Kiatpanichgij. "Bases of T-meshes and the refinement of hierarchical B-splines." preprint in arxiv: http://arxiv.org/abs/1401.7076
2 Dmitry Berdinsky, Tae-wan Kim, Cesare Bracco, Durkbin Cho, Bernard Mourrain, Min-jae Oh, Sutipong Kiatpanichgij. "Dimensions and bases of hierarchical tensor-product splines." *Journal of Computational and Applied Mathematics*. Vol. 257, pp. 86–104, 2014
3 Dmitry Berdinsky, Tae-wan Kim, Cesare Bracco, Durkbin Cho, Min-jae Oh, Yeong-hwa Seo, Sutipong Kiatpanichgij. "Iterative refinement of hierarchical T-meshes for bases of spline spaces with highest order smoothness." *Computer-Aided Design*. Vol. 47, pp. 96–107, 2014

4 Dmitry Berdinsky, Min-jae Oh, Tae-wan Kim, Bernard Mourrain. "On the problem of instability in the dimension of a spline space over a T-mesh." *Computers & Graphics*. Vol. 36, No. 5, pp. 507–513, 2012

3.17 From Quad Meshes to Quad Layouts

Leif Kobbelt (RWTH Aachen, DE)

Joint work of Kobbelt, Leif; Marcel, Campen; David, Bommes
URL http://www.graphics.rwth-aachen.de

The conversion of raw geometric data (that typically comes in the form of unstructured triangle meshes) to high quality quad meshes is an important and challenging task. The complexity of the task results from the fact that quad mesh topologies are subject to global consistency requirements that cannot be dealt with by local constructions. This is why recent quad meshing techniques formulate the mesh generation process as a global optimization problem. By adding hard and soft constraints to this optimization, many desired properties such as structural simplicity, principal direction alignment, as well as injectivity can be guaranteed by construction. A, in some sense, extreme form of quad meshing is the computation of quad layouts, where a coarse segmentation of the input surface into essentially rectangular patches is sought which also satisfies global consistency and shape quality requirements. While being structurally related, both problems need to be addressed by fundamentally different approaches. In my talk I will present some of these approaches and demonstrate that they can generate high quality quad meshes and quad layouts with a high degree of automation but that they also allow the user to interactively control the results by setting boundary conditions accordingly.

References

1 Marcel Campen, Leif Kobbelt *Quad Layout Embedding via Aligned Parametrization*. Computer Graphics Forum, 2014
2 Marcel Campen, David Bommes, Leif Kobbelt *Dual Loops Meshing: Quality Quad Layouts on Manifolds*. SIGGRAPH 2012, ACM Transactions on Graphics

3.18 Rational bilinear quaternionic parametrization of Dupin cyclides

Rimvydas Krasauskas (Vilnius University, LT)

Joint work of Olechnovic, Kliment; Krasauka, Rimvydas

Rational Bezier formulas with quaternion weights are introduced for parametrization of principal Dupin cyclide patches. Well-known geometric properties (Moebius invariance, offsetting, representation as a canal surface) and several new ones (Willmore energy, natural parametrizations) of Dupin cyclides can be derived using this quaternionic approach. An application example will be presented: surfaces for modeling voids and channels in large biomolecules.

3.19 Modeling with Ambient B-Splines

Nicole Lehmann (TU Darmstadt, DE)

The talk introduces a new approach for the generation of C^k approximants of functions defined on closed submanifolds for arbitrary k in N. In case a function on a surface resembles the three coordinates of a topologically equivalent surface in R^3, we even obtain C^k-approximants of closed surfaces of arbitrary topology. The key idea of our method is a constant extension of the target function into the submanifold's ambient space. In case the reference submanifolds are embedded and C^2, the usage of standard tensor product B-splines for the approximation of the extended function is straightforward. We obtain a C^k approximation of the target function by restricting the approximant to the reference submanifold. We illustrate our method by an easy example in R^2 and verify its practicality by application-oriented examples in R^3. The usage of B-splines not only guarantees full approximation power but also allows a canonical access to adaptive refinement strategies.

3.20 Bijection-Lifting For Surface Mapping

Yaron Lipman (Weizmann Institute, IL)

Joint work of Lipman, Yaron; Aigerman Noam; Poranne Roi
Main reference N. Aigerman, R. Poranne, Y. Lipman, "Lifted bijections for low distortion surface mappings," ACM Transactions on Graphics, 33(4:69), 12 pages, 2014; pre-print available at author's webpage.
URL http://doi.acm.org/10.1145/2601097.2601158
URL http://www.wisdom.weizmann.ac.il/~noamaig/html/projects/lifted/lifted.pdf

This work introduces an algorithm for computing low-distortion, bijective mappings between surface meshes. The algorithm receives as input a coarse set of corresponding pairs of points on the two surfaces, and follows three steps: (i) cutting the two meshes to disks in a consistent manner; (ii) jointly flattening the two disks via a novel formulation for minimizing isometric distortion while guaranteeing local injectivity (the flattenings can overlap, however); and (iii) computing a unique continuous bijection that is consistent with the flattenings. The construction of the algorithm stems from two novel observations: first, bijections between disk-type surfaces can be uniquely and efficiently represented via consistent locally injective flattenings that are allowed to be globally overlapping. This observation reduces the problem of computing bijective surface mappings to the task of computing locally injective flattenings, which is shown to be easier. Second, locally injective flattenings that minimize isometric distortion can be efficiently characterized and optimized in a convex framework. Experiments that map a wide baseline of pairs of surface meshes using the algorithm are demonstrated. They show the ability of the algorithm to produce high-quality continuous bijective mappings between pairs of surfaces of varying isometric distortion levels.

3.21 Compressed sensing and its application in geometry processing

Ligang Liu (University of Science & Technology of China – Anhui, CN)

Joint work of Liu, Ligang; Yang, Zhouwang; Chen, Falai; Deng, Jiansong
Main reference R. Wang, Z. Yang, L. Liu, J. Deng, F. Chen, "Decoupling Noises and Features via Weighted l_1-analysis Compressed Sensing," ACM Transactions on Graphics, 33(2:18), 12 pages, 2014; pre-print and additional data available at author's webpage.
URL http://doi.acm.org/10.1145/2557449
URL http://staff.ustc.edu.cn/~lgliu/Projects/2014_DecouplingNoise/default.htm

Compressed sensing (CS) and sparse representation have attracted considerable attention in areas of applied mathematics, computer science, and electrical engineering during the last few years. CS builds upon the fundamental fact that we can represent many signals using only a few non- zero coefficients in a suitable basis or dictionary. Nonlinear optimization can then enable recovery of such signals from very few measurements. We have demonstrated our recent works on geometry processing using sparse representation and sparse optimization.

3.22 Smooth Simplex Splines for the Powell-Sabin 12-split.

Tom Lyche (University of Oslo, NO)

This is a dummy text. Simplex splines are the natural generalization of B-splines to the multivariate case. Recently a simplex spline basis for C^1 quadratics on the Powell-Sabin 12-split was constructed. This basis has all the usual properties of univariate B-splines. In this talk we present work in progress dealing with C^3 quintic polynomials on PS 12. This piecewise polynomial on one triangle can be combined with neighboring elements to form a C^2 representation on any triangulation. We give several Simplex spline bases for this element. These bases form a nonnegative partition of unity, satisfy a Marsden-like identity, and the restriction of each basis element to the boundary edges of the macro element reduces to a standard univariate quinitc B-spline.

3.23 Similarities in parametric B-rep models: detection and applications

Geraldine Morin (ENSEEIHT – Toulouse, FR)

In this work, we identify and exploit the partial similarities within 3D objects represented by NURBS based B-rep models. Novel methods are introduced, on the one hand to detect the partial similarities [1], on the other hand to use these similarities for specific applications such as shape editing, compression and indexation of 3D objects [2, 3]. The number of 3D models available is increasing. To limit the time spent to create these models, the reuse and the adaptation of existing models becomes a prior choice. Thus, methods to ease storing, searching and exploiting these models are necessary. Partial similarities within 3D objects is common: many objects are composed of similar patches up to an approximated rotation, translation or symmetry. In a first phase, we introduce an approach similar to the Hough Transform to detect the partial similarities within NURBS-BRep models. This approach identifies not only similar patches but also the transformations that connect them. Two proposed filtering techniques make this approach flexible and able to adapt to special features of BRep models: a face-based to general cases and a point-based to identify transformations within a single face. Additionally, through the classification of isometries in transformations analysis, our approach can distinguish the nature of similar patches of a model, that is, the patches similar up to an approximated rotation, translation or symmetry. Additionally, 3D model indexation requires a canonical orientation of these models; the symmetry within a 3D object is a good orientation reference, coherent with the human perception. Accordingly, we use the partial symmetries to align 3D models and so reinforce the robustness of indexation methods.

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2 Quoc Viet Dang, Sandrine Mouysset, Geraldine Morin *Symmetry-Based Alignment for 3D Model Retrieval*. In : International Workshop on Content-Based Multimedia Indexing (CBMI 2014), Klagenfurt, 2014.
3 Quoc Viet Dang, Geraldine Morin, Sandrine Mouysset *Symmetry and Fourier Descriptor: A Hybrid Feature For NURBS based B- Rep Models Retrieval*. In : Eurographics Workshop on 3D Object Retrieval (3DOR), Strasbourg, 2014.

3.24 Spline spaces on topological complexes

Bernard Mourrain (INRIA Sophia Antipolis – Méditerranée, FR)

In geometric modeling and in applications such as isogeometric analysis, one is interested in the precise representation of geometric shapes and of functions on these shapes, Complex models made of simple pieces glued together according to a specific topology are often involved. We are interested in providing simple and efficient parametric representations of such models. Given a topological complex described by 2 dimensional cells and glueing relations along edges, we consider the space of piecewise polynomial functions on this complex with a given regularity across the edges. The regularity property across edges is specified by transition maps and C^k conditions through the composition with these transition maps. We describe constructions of such spline spaces over cell complexes with vertices of arbitrary, we analyse the dimension of the space of splines of bounded degree and some basis. Homological techniques used for planar subdivisions are extended to this context.

3.25 A Hermite interpolatory subdivision scheme for C^2-quintics on the Powell-Sabin 12-split

Georg Muntingh (SINTEF IKT Applied Mathematics – Oslo, NO)

Joint work of Lyche, Tom; Muntingh, Georg
Main reference T. Lyche, G. Muntingh, "A Hermite interpolatory subdivision scheme for C^2-quintics on the Powell-Sabin 12-split," Computer Aided Geometric Design, 2014, in press.
URL http://dx.doi.org/10.1016/j.cagd.2014.03.004

In order to construct a C^1-quadratic spline over an arbitrary triangulation, one can split each triangle into 12 subtriangles, resulting in a finer triangulation known as the Powell-Sabin 12-split. It has been shown previously that the corresponding spline surface can be plotted quickly by means of a Hermite subdivision scheme. In this talk we introduce a nodal macro-element on the 12- split for the space of quintic splines that are locally C^3 and globally C^2. For quickly evaluating any such spline, a Hermite subdivision scheme is derived, implemented, and tested in the computer algebra system Sage. Using the available first derivatives for Phong shading, visually appealing plots can be generated after just a couple of refinements.

3.26 Adaptive Refinement in Isogeometric Shape Optimization

Peter Noertoft (Technical University of Denmark – Lyngby, DK)

Joint work of Nørtoft, Peter; Dokken, Tor

Shape optimization deals with designing "best" shapes based on some notion of goodness. In engineering sciences, shape optimization problems are often constrained by partial differential equations (PDEs). In the context of PDE constrained shape optimization, isogeometric analysis is recent numerical methodology that provides a unified computational framework for designing shapes and solving PDEs. In this methodology, local refinement is crucial to ensure efficiency and accuracy of the method. This goes both for the geometric model to be optimized, and for the discretization on which the solution of the governing PDE is based. This talk presents some ongoing work on how to combine isogeometric shape optimization and local refinement through the use of Locally Refinable (LR) B-splines. The focus is on flow problems, where the governing PDE is the Navier-Stokes equations.

3.27 Isogeometric analysis at irregular points

Jörg Peters (University of Florida – Gainesville, US)

Joint work of Peters, Jörg; Thien Nguyen; Kęstutis Karčiauskas
Main reference T. Nguyen, K. Karčiauskas, J. Peters, "A Comparative Study of Several Classical, Discrete Differential and Isogeometric Methods for Solving Poisson's Equation on the Disk," Axioms, 3(2):280–299, 2014; related pre-print available at arXiv.
URL http://dx.doi.org/10.3390/axioms3020280
URL http://arxiv.org/abs/1406.4229v1

The iso-geometric approach has to date not been analyzed at irregular points (a.k.a. extraordinary points or star points) where more or fewer than four tensor-product splines meet smoothly. Since the smooth joining of spline (surface) pieces is governed by geometric continuity relations, it is natural to apply the concept of geometric continuity to constructing everywhere differentiable iso-geometric elements.

This presentation at the Dagstuhl workshop consisted of a comparative study by Thien Nguyen, Kęstutis Karčiauskas and Jörg Peters [1] of several classical, discrete differential and four (new) isogeometric methods and explained why geometrically continuous surface constructions yield iso-geometric elements that are differentiable also at irregular domain points [2].

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1 Thien Nguyen, Kęstutis Karčiauskas, and Jörg Peters. A comparative study of several classical, discrete differential and isogeometric methods for solving Poisson's equation on the disk. *Axioms*, 3(2):280–299, 2014.

2 Jörg Peters. Matched G^1-constructions yield C^1-continuous isogeometric elements, http://arxiv-web3.library.cornell.edu/pdf/1406.4229.pdf

3.28 Interactive Spacetime Control of Deformable Objects

Konrad Polthier (FU Berlin, DE)

Joint work of Hildebrandt, Klaus; Schulz, Christian; von Tycowicz, Christoph; Polthier, Konrad
Main reference K. Hildebrandt, C. Schulz, C. von Tycowicz, K. Polthier, "Interactive Spacetime Control of Deformable Objects," ACM Transactions on Graphics – SIGGRAPH 2012 Conference Proceedings, 31(4:71), 8 pages, 2012.
URL http://dx.doi.org/10.1145/2185520.2185567

Creating motions of objects or characters that are physically plausible and follow an animator's intent is a key task in computer animation. The spacetime constraints paradigm is a valuable approach to this problem, but it suffers from high computational costs. Based on spacetime constraints, we propose a framework for controlling the motion of deformable objects that offers interactive response times. This is achieved by a model reduction of the underlying variational problem, which combines dimension reduction, multipoint linearization, and decoupling of ODEs. After a preprocess, the cost for creating or editing a motion is reduced to solving a number of one- dimensional spacetime problems, whose solutions are the wiggly splines introduced by Kass and Anderson [2008]. We achieve interactive response times through a new fast and robust numerical scheme for solving the one- dimensional problems that is based on a closed-form representation of the wiggly splines.

3.29 Interactive geometric modeling under nonlinear constraints

Helmut Pottmann (KAUST – Thuwal, SA)

Joint work of Gomes, Alexandra; Jiang, Caigui; Pottmann, Helmut; Sun, Xiang; Tang, Chengcheng; Tomicic, Marko; Wallner, Johannes; Wang, Jun
Main reference C. Tang, X. Sun, A. Gomes, J. Wallner, H. Pottmann, "Form-finding with polyhedral meshes made simple," ACM Transactions on Graphics, 33(4), 9 pages, 2014.
URL http://doi.acm.org/10.1145/2601097.2601213

Aiming at shape modeling systems which support the user to satisfy constraints implied by function and fabrication of the designed product, we present a computational framework for handling nonlinear constraints within interactive geometric modeling tools. Our approach can be described as guided exploration of the constraint space whose algebraic structure is simplified by introducing auxiliary variables and ensuring that constraints are at most quadratic. Computationally, we perform a projection onto the constraint space which is biased towards low values of an appropriate energy which expresses desirable soft properties like fairness. Our main application is form-finding for polyhedral meshes, taking care of user-specified constraints like boundary interpolation, planarity of faces, statics, panel size and shape, enclosed volume and cost. Moreover, we present results on interactive design of freeform honeycomb structures, polyhedral patterns and developable B-spline surfaces.

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3.30 Rational Manifolds by Simple Ck Constructions

Hartmut Prautzsch (KIT – Karlsruher Institut für Technologie, DE)

Commenting on known work by other authors, I will discuss a construction of piecewise rational free form Gk surfaces with linear rational transition functions. Albeit rational, these surfaces can be represented by integral splines over affine planes which are extended to homogenous splines over the space. Conversely from any integral splines over affine planes, we can easily obtain a rational spline manifold. In particular, spherical Bernstein-Bezier surfaces introduced by Alfeld et al in 1996 can be described in this way and we can derive their common Bézier representation. For odd degree, the common and the spherical Bézier representation by Alfeld et al. have a simple geometric relationship.

3.31 Geometric Modeling in the Cloud

Ewald Quak (Technical University – Tallinn, EE)

This talk provided some information about two ongoing European projects which include the porting of geometric modeling approaches to Cloud computing environments.

One project is CloudFlow – Computational Cloud Services and Workflows for Agile Engineering – in the framework of Factories of the Future (FoF) that aims to ease the access to computationally demanding virtual product development and simulation tools, such as CAD, CAM, CAE, and make their use more affordable by providing them as engineering

Cloud services. CloudFlow (http://www.eu-cloudflow.eu) will organize two open calls to solicit application experiments to be run in the framework of CloudFlow, the first of which was published on 30 June, 2014.

The other project is IQmulus– A High-volume Fusion and Analysis Platform for Geospatial Point Clouds, Coverages and Volumetric Data Sets in the area of "Big Data" (http://www.IQmulus.eu). The IQmulus project addresses the integration of cutting edge computational approaches for data processing and visualization in Cloud infrastructures to make crucial information from large geospatial datasets available on time and to derive and visualize important knowledge for the relevant level of decision-making. IQmulus held its first scientific workshop processing Large Geospatial Data in July 2014 co-located with the Eurographics Symposium on Geometry Processing (SGP 2014).

3.32 SpiraLine: Interpolatory subdivision with log spirals

Jarek Rossignac (Georgia Institute of Technology, US)

We propose a new interpolatory subdivision scheme that produces curves in two and three dimensions, which we call spiraLines. We argue that the fairness of the spiraLine and the predictability of its behavior during interactive editing compare favorably to those offered by several other schemes. SpiraLines may be used to model circles and logarithmic spirals exactly and have many other benefits: they have local control, they are surprisingly stable when inserting additional control points and when sliding a control point tangentially along the curve, their curvature is fairly continuous and does not exhibit the ringing effect that plagues the fourPoint subdivision curves, an adequate spiraLine approximation of a given curve may often be designed using fewer control points than other interpolating curve would require, and finally spiraLines provide a consistent treatment of closed-loop curves and of the subdivision of the end-segments in non-closed curves.

3.33 Isogeometric Analysis with box-splines: a preliminary study

Maria Lucia Sampoli (University of Siena, IT)

B-spline and NURBS representations (with a tensor-product structure in 2D) are an effective tool originally developed in the context of geometric modeling, and they constitute the standard form of modern CAD software libraries.

Recently they have been successfully used in the so called *Isogeometric Analysis* to represent both geometry and physical fields for the solution of problems governed by partial differential equations. One of the main advantages of this new approach is the elimination of geometric-approximation error at even the coarsest level of refinement. In addition, the increased continuity of the NURBS basis has led to significant numerical advantages over traditional FEM methods.

On the other hand the tensor-product structure makes the modeling on rectangular regions a hard task, often accomplished by inserting unnatural singularities in the geometry map. A way to overcome this problem is to consider triangular topologies, even if dealing with completely general triangulations is quite difficult, because only in few cases suitable bases for the corresponding spline spaces are available. Moreover, their extension to the trivariate setting is computationally prohibitive in practice. Aim of the current work is therefore to investigate on the usage of suitable splines on regular triangulations (in particular on regular three-directional meshes), which can be seen as the natural bivariate generalization of univariate B-splines and can be extended to higher dimensions. Then, they can be seen as an intermediate step between tensor product structures and general triangulations and can provide an interesting alternative to NURBS in IgA.

In this talk the fist steps for the employments of box-splines in IgA will be discussed.

3.34 Mesh Denoising via L0 Minimization

Scott Schaefer (Texas A&M University – College Station, US)

Joint work of He, Lei; Schaefer, Scott
Main reference L. He, S. Schaefer, "Mesh denoising via L_0 minimization," ACM Transactions on Graphics – SIGGRAPH 2013 Conference Proceedings, 32(4:64), 8 pages, 2013.
URL http://dx.doi.org/10.1145/2461912.2461965

We present an algorithm for denoising triangulated models based on L0 minimization. Our method maximizes the flat regions of the model and gradually removes noise while preserving sharp features. As part of this process, we build a discrete differential operator for arbitrary triangle meshes that is robust with respect to degenerate triangulations. We compare our method versus other anisotropic denoising algorithms and demonstrate that our method is more robust and produces good results even in the presence of high noise.

3.35 From Solid Modeling to Material Modeling

Vadim Shapiro (University of Wisconsin – Madison, US)

Classical solid modeling techniques were designed to model curves, surfaces, and solids in support of traditional manufacturing. These techniques appear to be ill-suited for modeling of complex material structures, such as composites and random heterogeneous materials, that are increasingly important in modern manufacturing and engineering of materials. I will attempt to articulate some of the challenges in modeling of such material structures and speculate on possible approaches for addressing them.

3.36 Motorcycle Graph Enumeration from Quadrilateral Meshes for Reverse Engineering

Hiromasa Suzuki (University of Tokyo, JP)

Joint work of Suzuki, Hiromasa; Gunpinar, Erkan; Moriguchi, Masaki; Ohtake, Yutaka
Main reference E. Gunpinar, M. Moriguchi, H. Suzuki, Y. Ohtake, "Motorcycle Graph Enumeration from Quadrilateral Meshes for Reverse Engineering," Computer-Aided Design, Vol. 55, pp. 64–80, Oct. 2014.
URL http://dx.doi.org/10.1016/j.cad.2014.05.007

Recently proposed quad-meshing techniques allow the generation of high-quality semiregular quadrilateral meshes. This paper outlines the generation of quadrilateral segments using such meshes. Quadrilateral segments are advantageous in reverse engineering because they do not require surface trimming or surface parameterization. The motorcycle graph algorithm of Eppstein et al. produces motorcycle graph of a given quadrilateral mesh consisting of quadrilateral segments. These graphs are preferable to base complexes, because the mesh can be represented with a smaller number of segments, as T-joints (where the intersection of two neighboring segments does not involve the whole edge or vertex) are allowed in quadrilateral segmentation. The proposed approach in this study enumerates all motorcycle graphs of a given quadrilateral mesh and optimum one for reverse engineering is then selected. Due to the high computational cost of enumerating all these graphs, the mesh is cut into several sub-meshes whose motorcycle graphs are enumerated separately. The optimum graph is then selected based on a cost function that produces low values for graphs whose edges trace a large number of highly curved regions in the model. By applying several successive enumeration steps for each sub-mesh, a motorcycle graph for the given mesh is found. We also outline a method for the extraction of feature curves (sets of highly curved edges) and their integration into the proposed algorithm. Quadrilateral segments generated using the proposed techniques are validated by B-spline surfaces.

3.37 Applying Geometric Constraints in Reverse Engineering

Tamas Varady (Budapest University of Technology and Economics, HU)

This talk revisits and extends former work on reverse engineering with constraints; see [Benk et al. 2002]. Due to noisy data and the numerical nature of surface fitting, the majority of reconstructed CAD models need to be perfected to meet various engineering requirements in downstream applications. The surface elements must be accurately aligned and set to parallel, orthogonal, tangential, coaxial, and so on. This is hardly possible when surfaces are fitted individually, however, this can be accomplished when various groups of entities are fitted simultaneously while obeying a set of constraints.

This talk focuses on the automatic detection of likely geometric constraints and discusses the approximation of multiple point sets by solving large systems of equations. The proposed numerical method is capable to automatically disregard contradicting or over-determined constraints. The process can be significantly simplified by means of introducing the so-called auxiliary elements, which also help to set up global constraints for optimal orientation, best matching grid, full or partial symmetries, etc. The method will be illustrated by several examples showing reconstructed objects without and with constraints.

3.38 Computing Stable and Compact Representation of Medial Axis

Wenping Wang (University of Hong Kong, HK)

As a complete shape description, the medial axis of a geometric shape possesses a number of favorable properties–it encodes symmetry, local thickness and structural components of the shape it represents. Consequently, the medial axis has been studied extensively in shape modeling and analysis since its introduction by Blum in 1960's. However, the practical application of the medial axis is hindered by its notorious instability and lack of compact representation; that is, a primitive medial axis without proper processing is often represented as a dense discrete mesh with many spurious branches and a large number of vertices. In this talk I shall present some recent studies on computing stable and compact representations of the medial axes of 2D and 3D shapes. Specifically, techniques from mesh simplification, spline fitting, and optimal point sampling will be employed to compute a medial axis without spurious branches and represented by a small number of mesh vertices, while meeting specified approximation accuracy.

4 Working Groups

4.1 Workshop: 3D Printing

Ligang Liu and Ewald Quak

Main reference L. Gilpin, "3D printing: 10 companies using it in ground-breaking ways," Tech Republic, March 26, 2014.
URL http://www.techrepublic.com/article/3d-printing-10-companies-using-it-in-ground-breaking-ways/

3D printers have become popular in recent years and enable fabrication of custom objects for home users. The promise of moving creations from a virtual space into reality is truly tantalizing, and its applications go far beyond basic manufacturing and rapid prototyping. Many obstacles remain, however, for 3D printing to be practical and commonplace.

The workshop on 3D printing was organized by Ligang Liu (University of Science and Technology of China) and Ewald Quak (Tallinn University of Technology). It featured an introduction by Ewald Quak on some examples of the media attention 3D printing has found in recent times, and two presentations, one by Ligang Liu on Geometry Processing for 3D Printing and one by Gershon Elber (Technion) on Volumetric Modeling, both concerning some of the geometric challenges arising in 3D printing.

The lectures were followed by a general discussion on possible future activities of the scientific community represented at this Dagstuhl meeting in the area of 3D printing, like how 3D models need to be processed for the purpose of 3D printing and whether 3D printing forms a disruptive technology that will enable ordinary users, not just trained professionals, to generate, design and produce 3D models. Connections to another session at the meeting concerning material sciences were pointed out as 3D printing not only involves geometric design but also issues like deformable models, structural analysis and material properties.

Some comments by T. Grandine (Boeing) on the industrial geometric issues faced by Boeing concerning 3D printing were given as “There are several groups at Boeing pursuing 3D printing technology. Boeing is already using 3D printing for 1000s of different parts. The emerging AMF standard (Additive Manufacturing Format) for 3D printing is seriously flawed in many of the same ways as STL. In particular, it is overly reliant on triangle meshes as a means of transmitting geometries to printers. There is a real opportunity for our geometric modeling community to get involved and offer meaningful alternatives to what is currently under discussion.”

Some of the recent works on computational techniques of 3D printing are included below and have received considerable attention for assisting users to generate desired manufacturable objects.

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4.2 Workshop: The Future Challenges of Subdivision

Kai Hormann

In this workshop, we reviewed the state of the art of subdivision methods for geometric modelling and tried to identify the future challenges for this field of research. We agreed that subdivision algorithms for curves are well understood by now, but that we still lack good schemes and analysis tools for surfaces. In particular, we believe that non-linear or geometric surface schemes should be developed and examined, as they have the potential to provide reproduction of basic shapes (cylinder, spheres, etc.) and C^2-continuous and fair limit surfaces.

4.3 Workshop: Modeling heterogeneous, multi-scale, and graded material structures and behaviors

Jarek Rossignac and Vadim Shapiro

Contributors: Elaine Cohen (University of Utah, US), Tor Dokken (SINTEF, NO), Gershon Elber (Technion – Haifa, IL), Ioannis Z. Emiris (National Kapodistrian University of Athens, GR), Thomas A. Grandine (Boeing, US), Jens Gravesen (Technical University of Denmark, DK), Hans Hagen (TU Kaiserslautern, DE), Stefanie Hahmann (University of Grenoble/INRIA, FR), Jörg Peters (University of Florida – Gainesville, US), Hiromasa Suzuki (University of Tokyo, JP).

Novel additive manufacturing technologies provide support for producing parts and assemblies with a complex internal structure made of arbitrary compositions of increasingly small constituents of different materials. Rapid advances in natural sciences, in biomedical engineering, in material science and engineering, and in other emerging disciplines demand modeling and representation of heterogeneous, multi-scale, and graded structures. Although in principle, voxel-based representations could be used to represent such complex material compositions, they do not, by themselves, adequately support the design, editing, and analysis needs in most applications due to limited resolution, lack of analytic properties, lack of support for high-level design editing, and explosion in computational cost.

The workshop addresses the challenges that the Geometric Modeling research community must face in order to support modeling and representation of such material structures in variety of applications. It is also important to provide the Industry with the theoretical foundations and practical design and processing tools that are adequate for specifying the functional objectives and constraints, for generating automatically a detailed geometric model of the shape and of its internal structure that is independent of any particular manufacturing technology and that may vary through space, for editing the representation at different levels of detail, and for exporting it to specific analysis tools and specific manufacturing devices.

Here are examples of what we need to understand and develop:

- What physical and material properties and microstructures must be represented and at what scale of detail?

- What are the underlying principles for modeling multi-scale models and hierarchical material structures?
- To what extent it is possible to characterize physical properties of such structures by geometric computations?
- How to represent, at the high design level, the intended functionality and behavior of the entire assembly and the, possibly continuous, space varying distribution (gradation) of mechanical properties?
- How to model and visualize the responsive behavior of these structures, including those having more than one structural states (memory alloys) or those changing states (ceramics during baking)?
- How to specify, represent, analyze and visualize stochastic models defined by space varying distributions of density, shape, size, and orientation, material chunks?
- How to cope with the increased topological and computational complexity of materials with a periodic, although possibly irregular, internal structure that may follow prescribed contours?
- How to best support precise and local geometric queries needed for interactive visualization and analysis?
- What constructions and transformation are needed to effectively support modeling systems for such complex material structures?
- How does one architect a modeling system for design, simulation, and planning of such material structures?
- How to best incorporate the constraints imposed by the limitation of a particular manufacturing technology throughout the design phases, while preserving, as much as possible the integrity of the intentional specification model and its independent of a particular resolution or manufacturing technology?
- How to best design, visualize, and edit effective material properties and their gradation?
- How to extend, to these advanced material structures, the principles of dimensioning and tolerancing developed originally for mechanical assemblies, so that we can capture, visualize, and analyze the uncertainty in behavior resulting from variations in a particular manufacturing process?
- How to compare two different models and measure and visualize their differences, for example to identify equivalent parts or to compare the intended and the manufactured models?
- How to support the interactive design, simulation, and visualization of physical properties, behavior, shape, and structure and multiple levels of detail?

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