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SIAM
3600 Market Street, 6th Floor
Philadelphia, PA 19104-2688 U.S.
Telephone: 800-447-7426 (U.S. & Canada) +1-215-382-9800 (Worldwide)
meetings@siam.org

IP1

Neural Surface Representations

Recent advancements in deep learning have spurred significant interest in leveraging deep neural networks to represent 3D shapes, leading to the development of various surface representation methods. This talk will cover our research efforts on two key fronts: neural implicit surfaces and neural parametric surfaces. For neural implicit surfaces, we will discuss optimal training strategies for neural distance functions in shape modeling tasks, including surface fitting, CSG operations, and variational surface modeling. We will also explore their applications in 3D reconstruction from 2D image inputs and 3D shape generation. Next, we will delve into neural parametric surfaces, presenting their diverse formulations and applications in shape modeling and processing. Additionally, we will provide comparisons with conventional representations such as spline surfaces and subdivision surfaces, highlighting the advantages and challenges of neural approaches.

Wenping Wang
Texas A&M University, U.S.
wenping@tamu.edu

IP2

Skeleton-based Geometric Modeling

Skeletons are intuitive representations of a geometric shape that bridge the gap between explicit and implicit representations. Skeletons are very useful as shape descriptors, and also for controlling a shape, such as in animation. In 3D, the medial axis consists of 1D and 2D strata. In this talk, we review the classical and more recent approach to computing the skeleton in the discrete setting, and present how to insure insuring properties and structure similar to the continuous setting. We show the benefit of the skeleton structure in various applications, in particular, for filtering, an important task to overcome the main drawback of skeletons: the lack of robustness. We then present a method for generating a volume model from a skeleton. This parametric, continuous and piecewise smooth model is able to represent any tubular object. It is based on Bzier volumes, thus offering intuitive control and providing an interesting base model for IGA (isogeometric analysis). We study in detail the handling of junctions between tubular branches.

Géraldine Morin
University of Toulouse, France
geraldine.morin@toulouse-inp.fr

IP3

Life After MCAD

Mechanical CAD (MCAD) systems are used to define fully detailed geometric product models. They attempt to be a complete and accurate representation of the shape of a product, and are essential to modern product design and manufacture. In a simplified view of a product lifecycle, once an MCAD model is complete, the product is fully defined and ready for manufacture. This talk will describe the "afterlife" of MCAD models: how and why this master geometric description of a product is subsequently repurposed, reworked, and redefined, after the MCAD model has been frozen. For example, MCAD models may require idealisation and partitioning to produce a finite element simulations to validate product behaviour; they may need aggressive simplification to turn the geometry into simple shapes for incorporation into large geometric databases; they may need deformation to real-world measurements, or even morphing to suit a completely new purpose. Each of these scenarios comes with its own set of challenges, and underlying mathematical problems, with interesting links between them.

Henry Bucklow
International TechneGroup Incorporated (CADfix),
United King
henry.bucklow@iti-global.com

IP4

Human-Centered Geometry Processing

Humans can ubiquitously communicate and reason about both tangible and abstract shape properties. Artists can succinctly convey complex shapes to a broad audience using a range of mediums; and human observers can effortlessly analyze and agree on observed shape properties such as upright-orientation or style. While perception research provides some clues as to the mental processes humans employ when performing these tasks, concrete and quantifiable explanations of these actions are frequently lacking. Our recent research aims to quantify the geometric properties underlying human shape communication and analysis, and to develop algorithms that successfully replicate human abilities in these domains. In my talk I will survey our efforts in this space, focusing on ways to incorporate insights about human perception into algorithm design. My talk will include examples across a wide range of 2D and 3D geometry processing tasks, including shape orientation, VR interfaces for shape modeling, raw sketch consolidation; clip-art vectorization; clip-art reshaping; sketch-based 3D reconstruction; and style analysis and transfer for man-made shapes. The common thread in our proposed solutions to these problems is the use of insights derived from perception and design literature combined with derivation of quantitative properties via targeted human perception studies and machine learning from scarce data.

Alla Sheffer
University of British Columbia, Canada
sheffa@cs.ubc.ca

SP1

SIAM Activity Group on Geometric Design Early Career Prize Lecture: Robust and Sustainable Geometry Processing

Geometric data and signal processing have made remarkable progress in recent years, and the advent of modern AI tools promises an even brighter future. Many classical and contemporary methods, however, use vast amounts of data, considerable natural resources, and are not robust, which can necessitate running the same method multiple times with different inputs. These approaches can be expensive, environmentally harmful, and ultimately unsustainable. This talk explores efforts for robust and sustainable geometry processing methods that use all the information contained in input data, that promote the use of sustainable materials, and that make tools more efficient by ensuring their robustness. We will dive deeper into surface digitization from extremely low-resolution scans, training generative AI models without collecting terabytes of data, denoising functions on low-quality geometric domains, developing robust geometric algorithms with mathematical guarantees, and design tools for alternative manufacturing methods.

Oded Stein
USC
ostein@usc.edu

JP1

Joint Plenary Speaker with the SIAM/CAIMS Annual Meetings (AN25): Geometry for Computational Design and Fabrication

Geometry plays an important role in the design and fabrication of freeform shapes. This talk will illustrate the fruitful interplay between theory and applications in this area. It is shown how to combine classical and discrete differential geometry with numerical optimization to develop effective fabrication-aware design tools. Special emphasis is on the use of novel quad-mesh based discrete models and on the geometrically motivated initialization and regularization of optimization algorithms. Applications include paneling solutions for geometrically complex architectural skins, design and fabrication with materials which can be easily bent but hardly stretched, mechanical metamaterials, and how to program curvature into flat sheets via curved folding. The computational results are verified at hand of physical models.

Helmut Pottmann
King Abdullah University of Science and Technology, Saudi Ar
helmut.pottmann@gmail.com

CP1

Closed Formulae for the Relative Position of Two Conics

Efficient methods to determine the relative position of two conics are of great interest for applications in robotics, computer animation, CAGD, computational physics, and other areas. By using quantifier elimination over the reals, we present a method to obtain the relative position of a parabola or a hyperbola, and a coplanar ellipse, directly from the coefficients of their implicit equations and avoiding the computation of the corresponding intersection points. This characterisation is specially useful when the considered conics depend on one or several parameters.

Jorge Caravantes
Universidad de Alcala, Spain
jorge.caravantes@uah.es

Gema M. Diaz-Toca
Universidad de Murcia, Spain
gemadiaz@um.es

Mario Fioravanti
Universidad de Cantabria, Spain
mario.fioravanti@unican.es

Laureano Gonzalez-Vega
CUNEF Universidad
CUNEF Universidad
laureano.gonzalez@cunef.edu

CP1

Spherical Clothoid Splines

We present a spherical nonlinear spline interpolation algorithm using a spline primitive first studied by Mehlum, the spherical curve with geodesic curvature a linear function of arc length. The approach extends Leviens technique for clothoidal splines on the plane to a new space, leveraging tools from complex analysis.

Alexandru Ionut
independent researcher
alexandru.ionut172@gmail.com

CP1

A Smoothly Varying Quadrature Rule for Boundary Element Spline Discretizations: Application to the Stokes Problem

We introduce a novel quadrature rule for boundary element spline discretizations. Unlike traditional methods that classify integrals as weakly singular, nearly singular, or regular, our rule smoothly adapts based on the physical distance from singularities in the boundary integral kernels. This automatic calibration enhances accuracy and efficiency, particularly in B-spline-based discretizations. We apply the new rule to boundary element simulations of Stokes flow, a fundamental problem in fluid dynamics, porous media, and biomechanics, as well as a key step in solving more complex equations such as the Navier-Stokes equations.

Francesco Patrizi
University of Florence
francesco.patrizi@unifi.it

Cesare Bracco
Department of Mathematics - University of Florence
cesare.bracco@unifi.it

Alessandra Sestini
University of Florence
alessandra.sestini@unifi.it

CP1

Interpolation with Degree Seven Pythagorean-Hodograph Curves in Minkowski Space

The Minkowski Pythagorean hodograph (MPH) curve is a polynomial curve whose speed measured under the Minkowski metric is polynomial. It is a kind of generalization of the Pythagorean hodograph (PH) curve. PH curves have many nice geometric and algebraic properties. For example, the arc length of the PH curve can be represented in a closed form. And the offset curves of the PH curve are rational. Offset curves have many applications in CAGD such as NC machine tool path generation. When we try to compute offsets from the boundary curves of a domain, the trimming process is one of the most expensive processes. It is because all self intersection points of the untrimmed offsets should be found. But if we have the medial axis transform, the trimming process becomes almost trivial. The MPH curve is well adapted to the representation of the medial axis transform of a planar domain. In fact, if the smooth curve segment of the medial axis transform is written in the MPH form, the boundaries of the corresponding domain are easily computed as rational curves of the MPH curve parameter. Furthermore, just subtracting a constant value from the radius, the offset curves can be obtained as rational curves. In this paper, we examine the problem for constructing G^2 continuous MPH spline curves that are equipped with G^1 continuous Minkowski frames, and have a prescribed Minkowski length.

Francesca Pelosi
Department of Information Engineering and Mathematics
francesca.pelosi@unisi.it

CP1

G^1 Hermite Interpolation Method of Quadratic Log-Aesthetic Curves

Log-aesthetic curves are characterized by linear logarithmic curvature graphs with a slope of α [1]. These curves have relatively simple curvature functions and serve as generalizations of the Clothoid ($\alpha = -1$), Nielsen's spiral ($\alpha = 0$), logarithmic spirals ($\alpha = 1$), and the circle involute ($\alpha = 2$). Quadratic log-aesthetic curves, defined as curves with quadratic logarithmic curvature graphs (forming a parabola), were introduced in [2], along with a computational method utilizing error and imaginary error functions. In [2], it was noted that the G^1 Hermite interpolation method proposed in [1] is not applicable to these curves. In this talk, we propose a novel algorithm for G^1 Hermite interpolation of quadratic log-aesthetic curves. This method determines the parabola that satisfies the G^1 Hermite interpolation condition by specifying two slopes. [1] N. Yoshida and T. Saito, Interactive Aesthetic Curve Segments, The Visual Computer (Pacific Graphics), 22(9-11), pp.896-905, 2006. [2] N. Yoshida, T. Saito, Quadratic Log-Aesthetic Curves, Computer-Aided Design and Applications, 14(2), pp. 219-226, 2017.

Takafumi Saito
Tokyo University of Agriculture and Technology
txsaito@cc.tuat.ac.jp

Norimasa Yoshida
Nihon University
yoshida.norimasa@nihon-u.ac.jp

CP1

Curvature Monotonicity Region of Bzier Curves and its Application to G^2 Hermite Interpolation

In this talk, we first review our work on visualizing the curvature monotonicity region [1][2], which defines the region of a control point where the curvature of 2D and 3D Bzier curves varies monotonically. This method enables users to identify the region of a specific control point where curvature changes monotonically. The visualization process is performed in real time using GPU acceleration. We present examples of visualizing regions based on both a sufficient condition and the exact condition. For 3D curves, we provide visualizations of the regions in both 2D and 3D. Additionally, we demonstrate an application of this approach to G^2 Hermite interpolation that preserves curvature monotonicity for 2D rational cubic Bzier curves. In the proposed method, specific weights are automatically adjusted to ensure G^2 continuity, while curvature monotonicity is verified using the method introduced in [1][2]. By employing this approach, users can identify the curvature monotonicity region of a control point while maintaining G^2 continuity. [1] N. Yoshida, S. Sakurai, H. Yasuda, T. Inoue and T. Saito, Visualization of the Curvature Monotonicity Regions of Polynomial Curves and its Application to Curve Design, Computer-Aided Design and Applications, 21(1), pp.75-87, 2024. [2] T. Saito and N. Yoshida, Curvature monotonicity evaluation functions on rational Bzier curves. Computers & Graphics, 114, pp.219-229, 2023.

Norimasa Yoshida
Nihon University
yoshida.norimasa@nihon-u.ac.jp

Takafumi Saito
Tokyo University of Agriculture and Technology
txsaito@cc.tuat.ac.jp

MS1

Coarse Meshes as Spline Control Nets for (Geometry and) Engineering Analysis

Interpreting coarse meshes as Polyhedral-net Splines (PnS) or Subdivision Splines generalizes standard grid-based tensor-product splines. Capable of modeling free-form shapes, these splines avoid trimming and offer baked-in differentiability, without gaps in one framework. This second part focuses on computing the solution of second and fourth order partial differential equations on PnS or Subdivision surfaces.

Seth Barber
University of Florida
barber.seth@ufl.edu

MS1

A Preliminary Study on the Dimensional Stability Classification of Polynomial Spline Spaces over T-meshes

In this talk, we will introduce some results on the dimensional stability of polynomial splines over T-meshes, including thoughts on the definition of stability, a preliminary classification of dimensional stability, and some related applications of geometric modeling and isogeometric analysis.

Bingru Huang, Falai Chen
Department of Mathematics
University of Science and Technology of China
hbr999@ustc.edu.cn, chenfl@ustc.edu.cn

MS1

A Quadrature Algorithm for an Isogeometric Boundary Element Method on Non-Conforming Geometries

In conventional computer-aided design software, geometries are commonly described by non-uniform rational B-spline boundary representations. Using the same geometry basis functions, the isogeometric boundary element method provides a seamless bridge between design and simulation without the time-consuming volume meshing step. However, the employed boundary integral operators with their singular kernels pose significant challenges for implementation, especially in quadrature. In particular, when non-conforming meshes and parameterizations are provided, the task is to organize the integration domains in such a way that the well known Duffy trick can be applied. In this contribution, we propose a novel quadrature algorithm to handle non-matching parameterized geometries, while maintaining optimal convergence of the method.

Jürgen Dölz
University of Bonn
doelz@ins.uni-bonn.de

Maximilian Nolte
TU Darmstadt
maximilian.nolte@tu-darmstadt.de

Sebastian Schöps
Computational Electromagnetics Group (CEM), TU Darmstadt
Centre for Computational Engineering (CCE), TU Darmstadt
schoeps@gsc.tu-darmstadt.de

MS1

Coarse Meshes as Spline Control Nets for Geometry (and Engineering Analysis)

Interpreting coarse meshes as Polyhedral-net Splines (PnS) or Subdivision Splines generalizes standard grid-based tensor-product splines. Capable of modeling free-form shapes, these splines avoid trimming and offer baked-in differentiability, without gaps in one framework. This first part focuses on the geometry and explains the origin, and modeling ability of Polyhedral-net Splines (PnS) or Subdivision Splines.

Jorg Peters
University of Florida
jorg@cise.ufl.edu

MS2

The Geometry of Stackable Shells

We present a novel geometric framework for designing thin shells that conform to a given surface as closely as possible and consist of a collection of stackable blocks. The result will be a single geometric object that admits two distinct configurations: a deployed surface-like state, the *shell*, and a stacked volume-like state, the *stack*. This duality introduces a geometric link between freeform surfaces and volume foliations. Stackability has applications in freeform architecture and digital fabrication methods, such as hot blade cutting and conformal 3D printing, and allows for efficiency in material use, packing, storage and transportation.

Konstantinos Gavriil, Konstantinos Gavriil
SINTEF
konstatninos.gavriil@sintef.no, konstatninos.gavriil@sintef.no

MS2

Industrial Geometry Pipelines: Turning Cad Data into Actionable Insights

Manufacturers rely on digital geometric models to drive critical business and manufacturing decisions. Yet the geometry of the imagination - precise, continuous, and mathematically ideal - is always approximated through a digital representation such as boundary representations (BREP), triangle meshes, or a volumetric format. Each approach presents inherent tradeoffs between expressivity, accuracy, and computational flexibility. The quality of the business decisions that manufacturers make depends directly on their ability to glean insights and information from their 3D geometric data, which may depend again on representation. In this talk I will describe how Metafold approaches helping industrial manufacturers make critical decisions from 3D data.

Elissa Ross
Metafold 3D
elissa@metafold3d.com

Daniel Hambleton
Metafold 3D
USA
daniel@metafold3d.com¿;

MS2

Approximation by Meshes with Spherical Faces

Meshes with spherical faces and circular edges are an attractive alternative to polyhedral meshes for applications in architecture and design. Approximation of a given surface by such a mesh needs to consider the visual appearance, approximation quality, the position and orientation of circular intersections of neighboring faces and the existence of a torsion free support structure that is formed by the planes of circular edges. The latter requirement implies that the mesh simultaneously defines a second mesh whose faces lie on the same spheres as the faces of the first mesh. It is a discretization of the two envelopes of a sphere congruence, i.e., a two-parameter family of spheres. We relate such sphere congruences to torsal parameterizations of associated line congruences. Turning practical requirements into properties of such a line congruence, we optimize line and sphere congruence as a basis for computing a mesh with spherical triangular or quadrilateral faces that approximates a given reference surface.

Anthony S. Ramos-Cisneros, Alisher Aikyn
King Abdullah University of Science and Technology
anthony.cisneros@kaust.edu.sa, alisher.aikyn@kaust.edu.sa

Martin Kilian
TU Wein
kilian@geometrie.tuwien.ac.at

Helmut Pottmann
TU Wien and KAUST
helmut.pottmann@gmail.com

Christian Müller
TU Wein
cmueller@geometrie.tuwien.ac.at

MS2

Topological Offsets

We introduce Topological Offsets, a novel approach to generate manifold and self-intersection-free offset surfaces that are topologically equivalent to an offset infinitesimally close to the surface. Our approach, by construction, creates a manifold, watertight, and self-intersection-free offset surface strictly enclosing the input, while doing a best effort to move it to a prescribed distance from the input. Differently from existing approaches, we embed the input in a volumetric mesh, and insert a topological offset around the mesh with purely combinatorial operations. The topological offset is then inflated/deflated to match the user-prescribed distance, while enforcing that no intersections or non-manifold configurations are introduced. We evaluate the effectiveness and robustness of our approach on the Thingi10k dataset, and show that topological offsets are beneficial in multiple graphics applications, including

(1) converting non-manifold surfaces to manifold ones, (2) creation of nested cages/layered offsets, and (3) reliably computing finite offsets.

Daniel Zint
New York University
daniel.zint@nyu.edu

MS3

Reconstruction of Watertight Spline Surface Based on Global Parameterization

The problem of "dirty geometry" is a major issue in CAD/CAE, which poses a significant barrier to downstream tasks. Therefore, we aim to construct watertight spline surfaces globally. This is also the urgent need in reverse engineering and topological structure optimization. In reverse engineering, three-dimensional point clouds are obtained through scanning and need to be reconstructed into spline surfaces for further modification or processing. The results of topological structure optimization are often expressed in a discrete manner and also require reconstruction into spline surfaces. In this talk, we introduce a method for constructing spline surfaces based on global parameterization. The spline surfaces constructed by this method do not require trimming and have a global representation, thus avoiding the issue of non-watertightness. The main approach of this method is to use the Ricci flow algorithm for global parameterization, where the Riemannian metric plays a crucial role as the foundation for achieving global parameterization. To enhance the continuity of the reconstructed spline surfaces, we combine the Abel-Jacobi condition which controls singularities with the Bezier extraction method. This combination allows for the automatic construction of singularities and global adjustment of the spline surface basis functions, ensuring the reconstruction of globally parameterized spline surfaces that meet the smoothness criteria.

Na Lei
Dalian University of Technology
nalei@dlut.edu.cn

MS3

Isogeometric Topology Optimization of Thin-Walled Structures with Complex Design Domains

In this work, we present a novel isogeometric topology optimization (TO) method for shell structures that involve complex design domains. In particular, analysis-suitable unstructured T-splines (ASUTS) are used to represent complex design domains in a smooth and watertight manner. On top of such domains, minimum compliance is studied as the model problem, where the Kirchhoff-Love shell is used to compute the structural response and a generalized Cahn-Hilliard phase-field model is proposed to perform TO. Since both models are governed by high-order partial differential equations, ASUTS-based isogeometric analysis (IGA) is adopted for the spatial discretization due to its high-order smooth basis functions. Moreover, IGA provides the possibility to seamlessly integrate design, analysis, and optimization. To demonstrate the efficacy of the proposed method, we first perform several benchmark tests to show that the generalized Cahn-Hilliard model can naturally handle complex topological changes without special treatment. In the end, a couple of real-world engineering structures are studied to show the capability of the proposed method dealing with complex design domains.

Xiaodong Wei
Shanghai Jiao Tong University
xiaodong.wei@sjtu.edu.cn

MS3

DL-Polycube: Deep Learning Enhanced Polycube Method for High-quality Hexahedral Mesh Generation and Volumetric Spline Construction

In this paper, we present a novel algorithm that integrates deep learning with the polycube method (DL-Polycube) to generate high-quality hexahedral (hex) meshes, which are then used to construct volumetric splines for isogeometric analysis. Our DL-Polycube algorithm begins by establishing a connection between surface triangular meshes and polycube structures. We employ deep neural network to classify surface triangular meshes into their corresponding polycube structures. Following this, we combine the acquired polycube structural information with unsupervised learning to perform surface segmentation of triangular meshes. This step addresses the issue of segmentation not corresponding to a polycube while reducing manual intervention. Quality hex meshes are then generated using the polycube structures, together with octree subdivision, parametric mapping and quality improvement techniques. The incorporation of deep learning for creating polycube structures, combined with unsupervised learning for segmentation of surface triangular meshes, substantially accelerates hex mesh generation. Finally, truncated hierarchical B-splines are constructed on the generated hex meshes. We extract trivariate Bezier elements from these splines and apply them directly in isogeometric analysis. We offer several examples to demonstrate the robustness of our DL-Polycube algorithm.

Jessica Zhang
Department of Mechanical Engineering
Carnegie Mellon University
jessicaz@andrew.cmu.edu

Yuxuan Yu, Yuzhuo Fang
Donghua University
yuyuxuan@dhu.edu.cn, slccovey@outlook.com

Hua Tong
Carnegie Mellon University
huat2@andrew.cmu.edu

MS4

Application of Functional Maps for Mesh Registration and Morphing to Solve Partial Differential Equations on Industrial Components.

We propose an efficient method for computing continuous correspondences between non-rigid shapes using the functional maps framework. Our target application is to solve partial differential equations (PDEs) on industrial components observed via computed tomography, with an automatic boundary condition setup. We first show how the morphing of a reference mesh can be formulated directly in the functional (spectral) domain, without using landmarks, predefined correspondences, or external symmetry assumptions, as proposed in [Jing Ren, Adrien Poulenard, Peter Wonka, Maks Ovsjanikov,Continuous and Orientation-Preserving Correspondences via Functional Maps, 2018]. To improve correspondence accuracy, we rely on Wave Kernel Signature (WKS) descriptors, which are commonly used within the functional maps framework to capture intrinsic geometric features and enhance shape matching. The morphing process is further refined using Tikhonov regularization, ensuring accurate mesh correspondence while preserving the mesh quality required to solve partial differential equations. We present numerical results on turbine blade cores in aeronautics, which feature complex geometries with cooling channels that may shift due to manufacturing variations and operational constraints. The proposed approach improves simulation accuracy by capturing geometric variations, ensuring suitability for industrial applications.

Amelia Ferhat, David Ryckelynck
Mines Paris
amelia.ferhat@minesparis.psl.eu,
david.ryckelynck@minesparis.psl.eu

Henry Proudhon
Mines paris
henry.proudhon@minesparis.psl.eu

Clement Remacha
Safran
clement.remacha@safrangroup.com

MS4

Space-Filling Origami Tessellations Based on Triply Periodic Minimal Surfaces

Metamaterials are redefining the limits of conventional material performance, enabling extreme properties such as auxeticity, tunability, and multistability. Among the complex architectures that give rise to these properties, triply periodic minimal surfaces (TPMS) have emerged as a powerful design tool. TPMSs are smooth surfaces in Euclidean space with zero mean curvature and periodicity in three linearly independent directions. They have recently gained significant attention for their exceptional performance, offering high surface-area-to-volume ratios, efficient stress distribution, and tunable mechanical responses. Concurrently in metamaterials research, origami patterns have emerged as another popular subject area, promising to impart exotic, tunable properties to materials which they comprise. Leveraging hyperbolic tilings and minimal nets, this work synthesizes origami tessellations with the topology of TPMSs to produce novel, space-filling origami structures. This approach provides a way to engineer three-dimensional periodic structures based on the kinematics of two-dimensional folding patterns, where the functionalities of the latter may be conferred to the former in a highly symmetric manner. Several novel designs of cubic symmetry based on Schwartzs surfaces are introduced. These designs exhibit intriguing properties such as auxeticity and dynamic porosity control. Besides metamaterials, applications for these structures may be sought in design and architecture.

Daniel R. King
Aalto University
daniel.king@aalto.fi

MS4

Generalizing Hinged Tilings to 3D

Hinged tilings are mechanisms in the plane, composed of rigid polygons linked in pairs at the vertices. When the tiles rotate, they push and turn also the tiles adjacent to them. Cycles of hinged edges open into polygonal holes, and the entire structure expands globally. As auxetic mechanisms with a single degree of freedom are both visually appealing and satisfying to operate, a natural question arises: are there three-dimensional generalizations of these structures? An easy approach is to keep the tiles flat but assemble them into non-Euclidean surfaces embedded in 3-space. This can be done either by reducing or increasing the number of tiles meeting at a vertex. Reduction yields spherical surfaces, and increment yields hyperbolic ones. The spherical mechanisms shift between two polyhedra, whereas hyperbolic method produces networks of tunnels that shift between two skew apeirohedra. Although these surfaces are extrinsically three-dimensional as embeddings, they are still intrinsically two-dimensional. A genuinely three-dimensional generalization of a hinged tiling would replace polygonal tiles and zero-dimensional hinges with polyhedral blocks and one-dimensional hinges. I present examples of the cases above. They warrant investigation as they enhance the structural and kinetic stability of the mechanisms and suggest new architectural applications.

Taneli Luotoniemi
Aalto University
taneli.luotoniemi@aalto.fi

MS5

Quasi-Stationary Subdivision Schemes and Their Refinable Functions

A subdivision scheme is a fast local weighted averaging scheme for generating smooth curves/surfaces and its convergence plays a key role in analyzing properties of wavelets. Interpolating subdivision schemes and their refinable functions are of particular interest in CAGD and wavelet theory. In this talk, we study generalized interpolating refinable functions $\phi : \mathbb{R} \to \mathbb{R}$ such that ϕ satisfies the refinement equation $\phi(x) = M \sum_{k\in\mathbb{Z}} a(k)\phi(Mx - k)$ and has the generalized interpolation property $\phi(s_a) = 0$ and $\phi(s_a + k) = 0$ for all $k \in \mathbb{Z}\backslash\{0\}$, where $a : \mathbb{Z} \to \mathbb{R}$ is a mask, $M > 1$, and $s_a \in \mathbb{R}$. In this talk, we shall completely characterize a generalized interpolating refinable function in terms of its mask. More interestingly, such generalized interpolating refinable functions have a close connection to n_s-step interpolatory quasi-stationary subdivision schemes, which have never appeared in the literature yet. Our second result will characterize the convergence of quasi-stationary subdivision schemes. Examples will be given to illustrate their applications to CAGD. This talk is based on [B. Han, Interpolating refinable functions and n_s-step interpolatory subdivision schemes, Advances in Computational Mathematics, 50 (2024), Article No. 98] and [R. Lu and B. Han, Quasi-stationary subdivision schemes in arbitrary dimensions, (2024), arXiv:2410.06529].

Bin Han
Univesity of Alberta
Department of Mathematical and Statistical Sciences
bhan@ualberta.ca

MS5

A Modified Butterfly Subdivision Scheme with C^2-Smoothness over Regular Triangular Meshes

In this study, we present a novel method to improve the smoothness of the butterfly subdivision scheme over regular triangular meshes. Our approach unifies the Loop scheme and the classical butterfly scheme through the introduction of a tension parameter. The proposed scheme achieves fourth-order accuracy and generates C^2 limit surfaces for a suitable range of the parameter, while maintaining the support of the original butterfly scheme. Several numerical examples are provided to validate the theoretical results.

Byeongseon Jeong
Korea Advanced Institute of Science and Technology
South Korea
jeong@kmu.ac.kr

Hyoseon Yang
Kyung Hee University
South Korea
hyoseon@khu.ac.kr

Jungho Yoon
Dept. Mathematics, Ewha W. Univ.,
Seoul, S.Korea
yoon@ewha.ac.kr

MS5

Subdivision Schemes with High Quality Surface in Extraordinary Regions Through Tunned Repeated Local Smoothing Operations

Subdivision schemes are widely used in computer graphics and computer-aided design for representing models with arbitrary topology. Subdivision schemes exhibits various advantages compared with non-uniform rational B-splines, the de-facto standard for relevant industries. Nevertheless, one may still observe undesired oscillations of highlight lines and curvature distribution near extraordinary positions and further improvements are desirable for applications in high-end industrial design. In this talk, we present a family of tuned primal subdivision (TPS) schemes that are generalizations of odd-degree uniform B-spline surfaces for unstructured quadrilateral meshes of arbitrary topology. One level of subdivision of degree-p TPS-schemes is decomposed into one-step of simple topological splitting plus an additional $(p-1)/2$ series of repeated local smoothing operations. TPS-schemes produce subdivision surfaces with smooth and uniform highlight lines in extraordinary regions and near-G^2 continuity at extraordinary positions. A unified tuning framework is utilized to optimize subdivision rules of TPS-schemes for both topological splitting and smoothing operations near extraordinary vertices. The resulting TPS-schemes for any odd-degree are also convenient for practical applications as the optimized topological splitting and smoothing operations involve one-ring of neighbouring vertices only, without the need for large subdivision stencils.

Weiyin Ma
Mechanical and Biomedical Engineering
City University of Hong Kong
mewma@cityu.edu.hk

Xu Wang
School of Aerospace Engineering
North University of China
wangxu@nuc.edu.cn

MS5

Curvature Continuous Corner Cutting

Subdivision schemes are used to generate smooth curves by iteratively refining an initial control polygon. The simplest such schemes are corner cutting schemes, which specify two distinct points on each edge of the current polygon and connect them to get the refined polygon, thus cutting off the corners of the current polygon. While de Boor showed that this process always converges to a Lipschitz continuous limit curve, no matter how the points on each edge are chosen, Gregory and Qu discovered that the limit curve is continuously differentiable under certain constraints. In this talk, we show how these results can be extended, and how the limit curve can even be curvature continuous for specific sequences of cut ratios.

Claudio Mancinelli
University of Genoa, Italy
claudio.mancinelli@unige.it

Kai Hormann
Università della Svizzera italiana
kai.hormann@usi.ch

MS6

New Characterizations of Planar Quintic Pythagorean-Hodograph Curves

We present several new characterizations of planar quintic Pythagorean-Hodograph curves. The first two are algebraic and consist of two and three equations in terms of the edges of the Bézier control polygon as complex numbers. These equations are symmetric with respect to the edge indices and cover curves with generic as well as degenerate control polygons. We also discuss two geometric characterizations that both rely on just two auxiliary points outside the control polygon. One requires two (possibly degenerate) quadrilaterals to be similar, and the other highlights two families of three similar triangles. All four characterizations can be linked to the well-established counterparts for planar cubic Pythagorean-Hodograph curves. The key ingredient for proving the aforementioned results is a novel general expression for the hodograph of the curve. Moreover, we revisit the construction of Hermite-interpolating quintic PH curves and give a characterization of the singular cases when there are only three instead of the usual four solutions.

Kai Hormann
Università della Svizzera italiana
kai.hormann@usi.ch

Lucia Romani
University of Bologna, Italy
Department of Mathematics
lucia.romani@unibo.it

Alberto Viscardi
Università degli studi di Torino
Dipartimento di Matematica
alberto.viscardi@unito.it

MS6

Bounding Volumes of Gauss-Legendre Curves

Gauss-Legendre (GL) curves, defined by a recently introduced basis, have distinct geometric properties compared to classical Bzier curves. While they do not satisfy the convex hull property, their control polygons closely match the curve length. This leads to the question of how to effectively bound the region containing a GL curve. In this study, we examine methods for constructing bounding volumes for GL curves by analyzing their control polygons and basis function behavior. We establish upper and lower bounds for the curves difference from the control polygon and propose a bounding method that can be used in geometric modeling and applications.

Soo Hyun Kim
Pusan National University
5hkim@pusan.ac.kr

Hans-Peter Schröcker
University of Innsbruck
hans-peter.schroecker@uibk.ac.at

Hwan Pyo Moon
Dongguk University-Seoul
hpmoon@dongguk.edu

MS6

Motion Interpolation with Euler-Rodrigues Frames on Extremal Pythagorean-Hodograph Curves

We introduce a novel subset of spatial Pythagorean-hodograph (PH) quintic curves characterized by a unique extremal configuration in the quaternion space. For each generic set of C^1 Hermite motion data, there exist exactly four interpolants of these extremal PH curves, each of them matching the specified frames by its Euler–Rodrigues frame (ERF). The four extremal interpolants can be distinguished by the signs that are extracted from their generating quaternion polynomials, and are invariant under orthogonal transformations. Remarkably, not only are the extremal interpolants planar when applied to planar motion data, but they also demonstrate superior geometric properties in comparison to other PH quintic motion interpolants, particularly in terms of their bending energy and the angular variation of their ERF.

Song-Hwa Kwon
The Catholic University of Korea
skwon@catholic.ac.kr

Chang Yong Han
Kyung Hee University
cyhan@khu.ac.kr

MS6

Pseudo Convex Hull Property of Gauss-Legendre Curves

The Gauss-Legendre(GL) curve was developed to improve operability compared to the conventional Bézier curve during the design process using polynomial curves. Each edge of the GL control polygon specifies the tangent vector of the curve at the corresponding parameter. So the GL polygon provides the data for the hodograph of the desired curve to interpolate. Then the polynomial curve, which is the integral of the hodograph, can be expressed as the barycentric combination of the control points with the GL polynomials instead of the Bernstein polynomials. Since the GL polynomials are not always positive, the GL curves do not have the convex hull property as the Bézier curves do. We here address the pseudo convex hull property of the GL curves, namely, the GL curve belongs to the scaled convex hull of the control polygon with respect to the center of mass of all control points. We also present an algorithm to refine the scaled convex hull.

Soo Hyun Kim
Pusan National University
5hkim@pusan.ac.kr

Hans-Peter Schröcker
University of Innsbruck
hans-peter.schroecker@uibk.ac.at

Hwan Pyo Moon
Dongguk University-Seoul
hpmoon@dongguk.edu

MS7

Separable Shape Tensors: Emerging Methods for Pattern Recognition

Patterns in images manifest as coherent structures or shapes. Imaging methods produce segmented planar curves to facilitate inferences about changes in these patterns. To bolster metrology via imaging, we introduce novel pattern recognition formalisms combined with inference methods over large ensembles containing thousands of segmented curves. This is accomplished by accurately approximating eigenspaces of a composite integral operator to motivate discrete, dual representations collocated at quadrature nodes. Approximations are projected onto underlying matrix manifolds and the resulting separable shape tensors constitute rigid-invariant decompositions of curves into generalized (linear) scale variations and complementary (nonlinear) undulations. With thousands of curves segmented from pairs of images, we demonstrate how data-driven features of separable shape tensors inform explainable binary classification utilizing a product kernel metric: absent labeled data, learning interpretable feature spaces without high performance computation, and detecting discrepancies below cursory visual inspections.

Zach Grey
National Institute of Standards and Technology
Applied and Computational Mathematics Division
zachary.grey@nist.gov

Nicholas Fisher
Portland State University
nicholfi@pdx.edu

Andrew Glaws
National Renewable Energy Laboratory
15013 Denver West Parkway Golden, CO 80401-3305
andrew.glaws@nrel.gov

Gunay Dogan
National Institute of Standards and Technology
gunay.dogan@nist.gov

MS7

From Shapes to Shifts: An Elastic Framework for Detecting Changepoints in Animal Movement

Understanding animal movement patterns is critical in the study of behavioral ecology and conservation. Traditional changepoint detection methods often rely on scalar time seriesrepresentations of movement data, overlooking the functional nature of such trajectories and potentially missing valuable geometric insights. Here, we present a changepoint detection method designed for 2- and 3-dimensional animal movement trajectories (often in the form of open planar or space curves), using the elastic framework developed for the analysis of shapes and functional data. Due to our incorporation of the elastic metric, this method allows for the separation of amplitude(time-dependent) and phase (time) variability, enablingusers to easily align data in time in tandem with detecting different types of changes (e.g., changes in amplitude, phase, or both). We aim to provide the community with a mathematically coherent approach which preserves the intrinsic geometries of animal movement data, facilitatingmore intuitive comparisons, robust changepoint detection, and deeper insights into those detected behavioral transitions.

Carole Hall
Stony Brook University
carole.hall@stonybrook.edu

Derek Tucker
Sandia National Laboratories
jdtuck@sandia.gov

MS7

Testing the Manifold Hypothesis with Hades

High-dimensional data often exhibit low-dimensional structure, and a geometer's first intuition is to model the data using smooth manifolds. However this common assumption, called the "Manifold Hypothesis", is rarely verified to be true. In this talk I will introduce HADES, an unsupervised algorithm to detect data points that show non-manifold behaviour (i.e. singularities in data). This algorithm uses simple statistical methods that makes it much faster than existing topology-based alternatives. Using tools from differential geometry and optimal transport theory, we prove that HADES correctly detects singularities with high probability when the data sample lives on a transverse intersection of equidimensional manifolds. In computational experiments, HADES recovers singularities in synthetically generated data, branching points in road network data, intersection rings in molecular conformation space, and anomalies in image data.

Uzu Lim
Oxford
finnlimsh@gmail.com

MS7

Topological Shape and Data Analysis for Materials EBSD Imaging

We expound on formal principles combining Topological Data Analysis (TDA) and non-Euclidean distances between curves to motivate novel perspectives on the form and nature of pattern and shape in images. Specifically, TDA descriptors extracting persistent topological structures are combined with product submanifold learning of separable shape tensors (SST) to offer unique insights about images through the lens of a bifiltration. We offer principled and interpretable visualizations of feature extraction to augment modern imaging science aimed at a metrology of materials. Generally, this framework has significant potential to impact various fields where precise quantification of topology and shape is helpful in determining fundamental patterns and features of images.

Jeanie Schreiber
George Mason University
jschrei@gmu.edu

Zach Grey
National Institute of Standards and Technology
Applied and Computational Mathematics Division
zachary.grey@nist.gov

Adam Creuziger
National Institute of Standards and Technology
adam.creuziger@nist.gov

MS8

Simplifying the Spline Dimension Formula by Counting Line Intersections in the Wang-Shi Split

The Wang-Shi split allows for the construction of maximally smooth spline spaces on general triangulations for degree 3, 4, and it is a promising construction for arbitrary degree. The dimension of the space of maximally smooth splines on the Wang-Shi split of general degree is simplified by bounding the number of lines in the Wang-Shi split that intersect at the same point. The presentation will give an overview of the proof that for degree d at most $d + 1$ can intersect at the same point.

Andrea Bressan
IMATI CNR (Pavia)
andrea.bressan@imati.cnr.it

Thomas Takacs
Johann Radon Institut (RICAM)
thomas.takacs@ricam.oeaw.ac.at

MS8

Bzier Projection for THB-splines and Applications to Adaptive Refinement Methods

For non-linear or time-dependent adaptive numerical methods, the previous finite element solution is needed on the refined or coarsened mesh. To achieve this computationally efficiently, we previously introduced a Bzier projector for Truncated Hierarchical B-splines (THB-splines) [K. Dijkstra and D. Toshniwal, Approximation Theory and Numerical Analysis Meet Algebra, Geometry, Topology volume. 60 (2024), pp. 115-148], which also has applications in curve fitting or data compression. This creates collections of mesh elements, called macro-elements, and solves local projection problems on them. Subsequently, these local projections are smoothed to construct a global projection. Unfortunately, the existence of these macro-elements is not guaranteed and requires a given mesh to satisfy certain hard-to-check assumptions. In this talk, we discuss a simple, practical, easy-to-implement alternative based on p-boxes where refinement occurs only on a predetermined grid. The blocks of this grid can then be used to construct the macro-elements. Moreover, it is known that for convergence of adaptive methods using THB-splines, the mesh must belong to a finite admissibility class. We, therefore, introduce refinement and coarsening algorithms that maintain a predetermined admissibility class for a p-box mesh. We also present its application in adaptive numerical methods for the magnetohydrodynamics equations.

Kevin Dijkstra, Deepesh Toshniwal
Delft University of Technology
k.w.dijkstra@tudelft.nl, d.toshniwal@tudelft.nl

MS8

Nonlinear 2D Spline Quasi-Interpolants for Piecewise Smooth Function Approximation

Spline quasi-interpolation is well known to be a powerful and useful tool for the approximation of functions and data, important problem in many mathematical and scientific applications. A nice property, if compared to interpolation, is that it does not require the solution of any system of equations, particularly attractive in the bivariate case, where the number of data sites can be huge in practice. If the function to be approximated is smooth, a spline quasi-interpolant is able to well reconstruct it, but if the function has jump discontinuities, the approximating spline presents oscillations of magnitude proportional to the jump. In this talk we apply WENO (Weighted Essentially Non-Oscillatory) techniques to modify classical quasi-interpolants in spline spaces on criss-cross triangulations in order to avoid such oscillations near discontinuities and, at the same time, to maintain the high-order accuracy in smooth regions. We study the convergence properties of the proposed nonlinear quasi-interpolants and we provide some numerical and graphical tests confirming the theoretical results.

Francesc Aràndiga
Universitat de València, Spain
arandiga@uv.es

Sara Remogna
University of Turin
sara.remogna@unito.it

MS8

A General Framework for Constructing Geometrically Continuous Splines

In this talk, we will discuss a recent algebraic approach developed to study geometrically continuous spline spaces. In contrast to parametric spline functions, geometrically continuous splines are piecewise polynomial functions defined on a collection of patches that do not necessarily form a partition of a domain but are stitched together through transition maps. These functions are called Gr-splines if, after composition with the transition maps, they are continuously differentiable functions up to order r on each pair of patches with stitched boundaries. This type of spline has been used in computer-aided design and approximation theory to represent smooth shapes with complex topology. To establish an algebraic approach to these functions, we define Gr-domains and establish an algebraic criterion to determine whether a piecewise function is Gr-continuous on the given domain. In the proposed framework, we construct a chain complex whose top homology is isomorphic to the Gr-spline space. This complex generalizes the Billera-Schenck-Stillman homological complex used to study parametric splines. We show how previous constructions of Gr-splines fit into this new algebraic framework, illustrate how our approach works with concrete examples, and prove a dimension formula for the Gr-spline space in terms of invariants of the chain complex. We also present an algorithm, based on symbolic computation, to construct bases for Gr-spline spaces.

Angelos Mantzaflaris
Inria Sophia-Antipolis, University of Côte d'Azur
angelos.mantzaflaris@inria.fr

Bernard Mourrain
INRIA Sophia Antipolis
Bernard.Mourrain@inria.fr

Nelly Villamizar, Beihui Yuan
Swansea University
n.y.villamizar@swansea.ac.uk, beihui.yuan@swansea.ac.uk

MS9

Ball Mapper for Identifying Aromatic Chemical Compounds in Wine

This study introduces a novel approach combining two-dimensional gas chromatography (GCGC), high-resolution time-of-flight mass spectrometry (HR-TOF-MS), and topological data analysis (TDA) to identify unique chemical signatures in botrytized wines from Austria, Hungary, Slovakia, and France. Employing the ball mapper algorithm, we manage the high-dimensional data generated by HR-TOF-MS, simplifying the complex dataset into a representative set of chemical compounds for each wine. This method allows us to visualize and analyze chemical diversity and relationships in a more accessible two-dimensional form, facilitating the identification of distinct chemical profiles unique to wines from different regions. The application of this technique not only enhances our understanding of the compositional variations in European wines but also demonstrates the potential of TDA in analytical chemistry for complex mixture analysis such as food authentication and environmental studies. Our findings provide a new perspective on the standard analytical approaches, offering advancements in the field of computational geometric design applied to chemometrics.

Jooyoung Hahn
Czech Technical University in Prague
jooyoung.hahn@fjfi.cvut.cz

MS9

Effective Data Reduction for Persistent Homology and Its Applications

Topological Data Analysis (TDA) has proven invaluable for revealing hidden structures in large or high-dimensional data, yet its application often faces computational bottlenecks. In 2025, Choi et al.([1]) introduced the Characteristic Lattice Algorithm (CLA), a method that reduces dataset size while preserving critical topological features. However, CLA struggles to handle noisy datasets effectively. We address this challenge by presenting the Refined Characteristic Algorithm (RCLA), which mitigates noise while retaining essential topological insights. By tuning parameters, users can balance geometric fidelity and computational efficiency according to their needs. We further demonstrate the algorithms effectiveness in classification tasks on sizable, noise-affected datasets, confirming that RCLA processes massive data without sacrificing key structural information. Our approach highlights a practical pathway for scalable TDA, broadening its applicability to real-world problems where noise and data size are critical considerations.

Semin Oh
Kyungpook National University
Daegu, Republic of Korea
semin@knu.ac.kr

MS9

Detection of Anomalous Morphology in Neuroimages

We consider the problem of unsupervised detection of anomalous morphology (anatomical shape) in neuroimages. Representing morphology by diffeomorphic image warps, we model "normal' shape variation and apply a new method for detection of outliers and out-of-distribution samples, based on Bayesian convolutional neural networks.

Tanya Schmah
University of Ottawa
tschmah@uottawa.ca

MS10

Hierarchical Almost C1 Splines

Spaces of splines of C^1 continuity defined on multipatch geometries are a desirable tool in order to construct isogeometric methods to solve fourth order differential problems on complex domains. Moreover, if the space allows local refinement, it is natural to obtain an adaptive version of such methods. We propose to achieve these features by combining the construction presented in [T. Takacs, D. Toshniwal, Almost-C^1 splines: Biquadratic splines on unstructured quadrilateral meshes and their application to fourth order problems, Comput. Methods Appl. Mech. Engrg. 403, 2023] with the hierarchical framework, in order to allow local refinement also in the solution of fourth-order problem. This result requires to consider some theoretical aspects, such as the only partial nestedness of the biquadratic almost-C^1 spaces on the different levels of the hierarchy, and the linear independence of their basis. We will present a selection of examples showing the performances of the constructed isogeometric methods.

Cesare Bracco
Department of Mathematics - University of Florence
cesare.bracco@unifi.it

Carlotta Giannelli
University of Florence
Italy
carlotta.giannelli@unifi.it

Michelangelo Marsala
Deoartment of Mathematics - University of Florence
michelangelo.marsala@unifi.it

Thomas Takacs
Johann Radon Institut (RICAM)
thomas.takacs@ricam.oeaw.ac.at

Deepesh Toshniwal
Delft University of Technology
d.toshniwal@tudelft.nl

MS10

Rational Bézier Complex Curves

The real plane can be described using the complex structure as a complex line. Many properties remain the same on using this complex description, but other ones arise from the fact that the projective group of the real plane is not the same and is neither included in nor comprises the projective group of the complex line. The obvious example is that the complex group includes inversion, whereas the real group does not. This amounts to new geometry when the complex structure is considered. In the case of rational Bézier curves the key feature is that weights are no longer real, but complex. This possibility has been explored in several papers in the literature. For instance, circumferences arcs are of degree one as complex curves, but of degree two as real curves. In this talk we would like to emphasize the differences between both representations of rational plane curves, the relation between them and the possibilities provided by the use of the complex projective group.

Leonardo Fernandez-Jambrina
Universidad Politécnica de Madrid, Spain
leonardo.fernandez@upm.es

MS10

Shape Interpolation Via Discrete Geodesic Calculus on Planar Triangular Meshes

From computer graphics to 3D modelling, creating smooth transitions between shapescommonly known as shape interpolationis a critical task that comes with unique challenges depending on the chosen shape representation. In this talk, we explore the Riemannian structure of planar triangular meshes to address the interpolation problem, which involves solving a two-point boundary value geodesic equation. To overcome the complexities of using shooting methods in this context, we developed a discrete geodesic calculus that employs an inexpensive dissimilarity measure which approximates the Riemannian distance to transform the problem into a nonlinear ill-posed optimisation problem.

Estefania Loayza-Romero
University of Strathclyde
estefania.loayza-romero@strath.ac.uk

MS10

The Sharpness Condition for Constructing a Finite Element from a Superspline

This talk addresses the sharpness conditions for constructing C^r conforming finite element spaces from a superspline spaces on general simplicial triangulations. We introduce the concept of extendability for the pre-element spaces, which encompasses both the superspline spaces and the finite element spaces. By examining the extendability condition for both types of spaces, we provide an answer to the conditions regarding the construction. A corollary of our results is that constructing C^r conforming elements in d dimensions should in general require an extra $C^{2^s r}$ continuity on s-codimensional simplices, and the polynomial degree is at least $(2^{dr}+1)$.

Qingyu Wu
Peking University
wu_qingyu@pku.edu.cn

MS11

Learning and Shape Analysis of Pose Image Manifolds

Despite the high-dimensionality of images, the sets of images of 3D objects have long been hypothesized to form low-dimensional manifolds. What is the nature of such manifolds? How do they differ across objects and object classes? Answering these questions can provide key insights in explaining and advancing success of machine learning algorithms in computer vision. This paper investigates dual tasks – learning and analyzing shapes of image manifolds – by revisiting a classical problem of manifold learning but from a novel geometrical perspective. It uses geometry-preserving transformations to map the pose image manifolds, sets of images formed by rotating 3D objects, to low-dimensional latent spaces. The pose manifolds of different objects in latent spaces are found to be nonlinear, smooth manifolds. The paper then compares shapes of these manifolds for different objects using Kendall's shape analysis, modulo rigid motions and global scaling, and clusters objects according to these shape metrics. Interestingly, pose manifolds for objects from the same classes are frequently clustered together. The geometries of image manifolds can be exploited to simplify vision and image processing tasks, to predict performances, and to provide insights into learning methods.

Ben Beaudett
Florida State University
Dept of Statistics
bbeaudett@fsu.edu

Shenyuan Liang, Anuj Srivastava
Florida State University
sliang2@fsu.edu, anuj@stat.fsu.edu

MS11

High-Dimensional Quasiconformal Mapping Problems and Their Applications

Computational Quasiconformal Geometry has emerged as a powerful tool in imaging sciences by reformulating imaging problems as mapping problems. While traditional quasiconformal mappings are confined to 2D Riemannian manifolds, this work extends the framework to high-dimensional spaces. We introduce the concept of n-D Quasiconformality, a geometric quantity that characterizes high-dimensional mappings. Leveraging this concept, we propose a method to reconstruct the corresponding mappings by solving an elliptic partial differential equation (PDE). This novel approach provides a robust foundation for processing and analyzing high-dimensional mappings. Furthermore, we demonstrate the applicability of the proposed method to various imaging problems, showcasing its potential to advance the field of imaging sciences. This work is supported by the HKRGC GRF.

Ronald Lok Ming Lui
Department of Mathematics
The Chinese University of Hong Kong
lmlui@math.cuhk.edu.hk

MS11

Density-Equalizing Quasi-Conformal Mapping with Applications

Density-equalizing maps, driven by prescribed density information, often lack control over geometric distortions and bijectivity, particularly for surfaces with complex topologies. To address these issues, we propose a novel method for computing bijective density-equalizing quasiconformal(DEQ) flattening maps for connected open surfaces. Our approach formulates the density diffusion process as a quasiconformal flow, effectively controlling angle distortions and ensuring bijectivity through energy minimization with the Beltrami coefficient. We introduce an iterative scheme to optimize the shape of the target planar circular domain and the density-equalizing quasiconformalmap, enabling optimal parameterization of multiply-connected surfaces. Furthermore, our method extends to compute spherical density-equalizing maps for genus-0 closed surfaces. Additionally, landmark constraints can be incorporated into our proposed method to achieve consistent feature alignment. Using proposed methods, a large variety of bijective density-equalizing parameterizations can be achieved. Applications to surface registration, remeshing, and data visualization are presented to demonstrate the effectiveness of our methods.

Zhiyuan Lyu
The Chinese University of Hong Kong
zylyu@math.cuhk.edu.hk

MS11

Statistical Shape Analysis with Geomstats

Geomstats is an open-source Python package for computations and statistics on Riemannian manifolds. It provides object-oriented and extensively unit-tested implementations. Manifolds can be equipped with Riemannian metrics with associated exponential and logarithmic maps, geodesics, and parallel transport. Building on this general framework, the shape module implements widely used shape spaces, such as the Kendall shape space and elastic spaces of discrete curves and surfaces, by leveraging the abstract mathematical structures of group actions, fiber bundles, and quotient spaces. The Riemannian geometry tools enable users to compare, average, and interpolate between shapes belonging to a given shape space. These essential operations can then be used to perform statistics on shape data. In this talk, we will present the object-oriented implementation of the shape module along with illustrative examples and demonstrate its use in performing statistics on shape spaces.

Luis Pereira
University of Southern California
luisfpereira@ucsb.edu

PP1

Stackability of Architectural Freeform Surfaces

Surface stackability, the property of surfaces to be decomposed into stackable components (essentially, geometrically similar panels), is largely unexplored. We develop a mathematical framework as well as computational design tools for freeform surface stackability, unlocking the potential for advanced digital fabrication workflows such as hot blade cutting. To achieve this, the relationship between local surface properties and volumes is explored, such as curvature variation and volume sectional curvature, surface curves and volume foliations, etc. We identify minimizing paths for volume/curvature variation to define surface vector/cross fields for discretization and optimization. Several methods for rationalizing freeform surfaces are examined for optimal stackability search, and different settings are considered: enforcing smoothness, stacking adjacent or non-adjacent elements, flipping elements, introducing auxiliary slices for better stacking, etc. We formulate an optimization problem to enhance stackability, considering objective functions like total volume and curvature variation. Constraints include fabrication considerations, e.g. panel regularity and consistent similarity between consecutive panels. Specially relevant surface types are addressed, including ruled, developable, periodic and Weingarten surfaces. We assess their stackability and provide optimal decompositions for various fabrication methods. This research is part of the EIC pathfinder project STACK.

Ander Chocarro Salaberria
Technical University of Denmark (DTU)
Compute department

achsa@dtu.dk

PP1

Vemos: Visual Explorer for Metrics of Similarity

Similarity and dissimilarity metrics are a fundamental component of many tasks requiring the analysis and comparison of complex, often visual data. Applications ranging from computer vision to forensics require ways to effectively identify images, find clusters or outliers in data sets, or retrieve data items similar to a query item. However, finding an effective metric for a specific task is challenging due to the complexity of modern data sets and the myriad of possible similarity metrics arising from that complexity. We present VEMOS, a Python package that provides an accessible graphical user interface (GUI) for the evaluation of such comparison metrics. VEMOS provides user-friendly ways to examine individual data items or groups in a data set alongside analyses of metrics performance on the whole data set, such as clustering, multi-dimensional scaling, and retrieval performance analyses. VEMOS aims to help researchers and practitioners evaluate multiple comparison metrics (of similarity or dissimilarity) on rich, diverse data sets.

Gunay Dogan
National Institute of Standards and Technology
gunay.dogan@nist.gov

PP1

Scikit-Shape: Python Toolbox for Image and Shape Analysis

We introduce a Python package for image segmentation and shape analysis. Our package implements various building blocks to solve such problems, including algorithms for geometric regularization, elastic matching, adaptive discretization, and fast Newton-type minimization schemes. The package leverages the NumPy/SciPy ecosystem, making them as easy to use as Matlab, also compatible with existing Python tools. Our algorithms is freely available as an open source package for the research community at: http://scikit-shape.org

Gunay Dogan
National Institute of Standards and Technology
gunay.dogan@nist.gov

PP1

Modelling with 3D Elastica

Hot blade cutting utilizes a heated elastic rod, called blade, that is bent and twisted by two robotic arms to introduce freeform cuts through foam blocks. The shape of the blade will be that of an elastic curve. Planar elastic curves have been used for approximating a given curve segment and rationalizing doubly curved surfaces, but they do not fully exploit the potential of 3D elastic curves. 3D elastic curves increase the design space of their planar counterparts. We present an algorithm for approximating a given curve segment by a 3D elastic curve. Our approach is based on obtaining a solution for the boundary value problem for 3D elastic curves and depends on an analytic representation of the space of elastic curve segments, together with a geometric method for obtaining a good initial guess for the approximating curve. Finally, we optimize reducing the elastic energy to find the approximating elastic curve. This work lays the foundation for applications in digital fabrication, enhancing precision and efficiency in creating complex freeform structures.

Marc Isern
Technical University of Denmark (DTU)
misha@dtu.dk

PP1

Biomimetic Fiber-Reinforced Foam: A High-Strength, Low-Density and Humidity-Responsive Material for Scalable Applications

Biomimetic design, inspired by natural structures, allows us to develop advanced materials. This research draws on the anisotropic closed-cell structure of wood to create a dynamic foam that exhibits material properties characterized by high strength and low density. The bubbles of the fiber reinforced foam are elongated using temperature dependent viscosity of methylcellulose and constricted drying. This method induces anisotropic alignment, improving the foams yield strength by up to 64 times along the primary axis compared to the cross direction. Observations concluded that the oriented fiber-reinforced structures exhibited load-bearing capacity and resilience in bending. Additionally, the foam undergoes repeatable, humidity-driven dynamics: in a 59 cm x 39.5 cm x 36 cm closed environment, 10 cm foam samples bend up to 180° over approximately 2 minutes in response to rising humidity and returns to their original position in around 2 minutes as humidity decreases. The proposed novel foam manufacturing process can be easily scaled up from laboratory trials to industrial production volumes. Its adaptability to curved shapes make it a promising option for applications that require lightweight, durable components in extended lengths and flexible design specifications. Current research aims to scale this material into adaptive structures 1-3 m in size by exploring structural geometries through curved-crease folding and modular minimal surfaces.

Julian Smith
Thomas Jefferson University
julian.smith@students.jefferson.edu

Jordan Dornak, Karen Charlot-Wauquier, Juha Koivisto
Aalto University
danae.dornak@aalto.fi, karen.charlot-wauquier@aalto.fi, juha.koivisto@aalto.fi

PP1

Generative Design for Compliant Mechanisms Using Agentic AI

In generative design for load-bearing components, most advances target rigid systems. Yet, the growing use of compliant mechanisms is limited by manual, trial-and-error methods that cannot easily balance competing criteria—region-specific flexibility and stiffness, multi-degree-of-freedom motion, reaction force, and fatigue life. We introduce a novel generative design software for 3D compliant mechanisms that overcomes these challenges. Our approach begins with a custom structural solver that produces a comprehensive dataset to train a surrogate solver, replicating full solver behavior with minimal overhead. This surrogate achieves roughly 10x speed improvement and an error rate below 10% compared to legacy tools like Ansys and Solidworks. Integrated with a novel spatially aware, agentic AI framework, the system autonomously optimizes the design space, generating mechanism geometries with controlled, predictable bending behavior that meet diverse performance objectives. Rapid surrogate evaluations enable iterative design cycles at unprecedented rates. We present case studies that benchmark accuracy, generalizability, and speed, and demonstrate potential applications in robotics, aerospace, biotech, and adaptive systems design.

Ethan Wicko
Transcend Mechanics LLC
ethan.j.wicko@gmail.com