

Order and Disorder in Random Geometries

Hyperuniformity and
Topological Data Analysis

Abstract Booklet



6–10 July 2026



Schloss Reisensburg, Günzburg, Germany

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Acknowledgments

This workshop is hosted by the Institute of Stochastics at Ulm University and supported by the Deutsche Forschungsgemeinschaft (DFG) through the priority program SPP 2265 "Random Geometric Systems", the Initiative and Networking Fund of the Helmholtz Association under the call Helmholtz Young Investigator Groups (VH-NG-19-34, DataMat), the DLR, and the ANU.



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Michael A. Klatt, Vanessa Robins, Evgeny Spodarev

Organising team

Carolina Vieira Fernandez (Secretariat)

Christian Bair, Mikhail Chebunin, Vsevolod Chernyshev, Patrick Falk, Albert Fitz, Phillip Gräfensteiner, Yanzhi Guo, Michael Juhos, Luca Lotz, Duc Nguyen, Dominik Pabst, Chris Reinke, Joel Steinegger, Ilja Sukhanov.

Foreword

Dear participants,

It is our great pleasure to welcome you to the workshop “Order and Disorder in Random Geometries: Hyperuniformity and Topological Data Analysis”, taking place from 6 to 10 July 2026 at Schloss Reisenburg in Günzburg, Germany. This year, we are delighted to bring together 54 participants from 12 countries: Australia, Austria, Czech Republic, Denmark, France, Germany, Italy, Serbia, Singapore, Spain, the United Kingdom, and the United States. The participants come from a broad academic and research background, including mathematics, physics, statistics, data science, topological data analysis, stochastic geometry, and related fields, representing universities and research institutions across Europe and beyond. Invited speakers are world-renowned experts in their fields, and we especially look forward to a fruitful exchange of ideas between established and young researchers as well as PhD and masters students.

The scientific programme includes 7 plenary lectures, 26 invited talks, and 16 poster presentations. The contributions span a rich range of subjects, including hyperuniformity, stochastic and random geometry, topological data analysis, persistent homology, point processes, random fields, quasicrystals, disordered and active matter, spatial statistics, and applications in materials science, biological systems, machine learning, and data-driven pattern discovery. Together, these topics highlight the workshop’s central aim: to connect mathematical theory, computational methods, and applications in the study of order, disorder, and structure in complex systems.

We gratefully acknowledge the support of our sponsors and supporting institutions. The conference is organized by Ulm University and supported by the German Aerospace Center (DLR) and the Australian National University. It is funded by the German Research Foundation (DFG) through the Priority Programme SPP 2265 “Random Geometric Systems”, as well as by Ulm University, the DLR, and the Initiative and Networking Fund of the Helmholtz Association under the call Helmholtz Young Investigator Groups (VH-NG-19-34, DataMat).

Schloss Reisenburg offers a wonderful setting for exchange, discussion, and new ideas. We warmly welcome all participants and wish everyone an inspiring and productive workshop in this very special venue.

Michael Klatt, Vanessa Robins, Evgeny Spodarev

Conference Venue

The workshop takes place at Schloss Reisenburg, the Science Centre of Ulm University, located on an idyllic hill near Günzburg. The castle serves as a conference and retreat venue for the university and is dedicated to promoting scientific collaboration at regional, national, and international levels, as well as exchange between universities, research institutions, business, politics, and administration.



Schloss Reisenburg combines a historic atmosphere with modern conference infrastructure. The castle hill has been settled since prehistoric times; historical and archaeological records mention the site as early as the 7th century, and since 1997 Schloss Reisenburg has belonged to Ulm University. Today, it offers lecture halls, seminar rooms, group work rooms, meeting areas for coffee breaks and informal discussions, and the “Historische Klause” for evening exchange. For our workshop, the castle accommodation will be fully used by participants. It provides 50 guest rooms for this event: 13 single rooms in the Nordtrakt, 32 single rooms in the Südtrakt, and 5 double rooms. Full board is provided

for participants; breakfast, lunches, dinners, coffee breaks, and the conference dinner will be served by the Schloss restaurant/kitchen.

The venue also provides modern communication facilities. Schloss Reisenburg is connected directly to the Ulm University data network and the internet. WLAN is available in all public areas, and internet access is also listed for guest rooms, the Roter Saal, the conference rooms, and the old reception area on the second floor.

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Programme

Monday, 6 July 2026

Time	Session
08:00	<i>Check-in / arrivals from this time onwards</i>
09:30–12:00	<i>Registration</i>
12:00–13:45	<i>Lunch – 2-course meal</i>
13:50–14:00	<i>Opening</i>
14:00–15:00	Plenary 1: Steinhardt, Paul J. (Princeton University) Recent results on Anderson localization and photonic band gap properties in stealthy hyperuniform media
15:00–15:30	Byléhn, Mattias (University of Vienna) Hyperuniformity in negative curvature
15:30–16:00	<i>Coffee break</i>
16:00–16:30	Schroeder-Turk, Gerd E. (Murdoch University) Random bicontinuous structures: local curvature and domain size uniformity
16:30–17:00	Schmiedeberg, Michael (FAU Erlangen–Nürnberg) Quasicrystals with large rotational symmetries: Amorphous-like on small but ordered at large lengths scale
17:00–17:30	<i>Coffee break</i>
17:30–18:00	Smith, Ana-Suncana (FAU Erlangen–Nürnberg) Lloyd optimisation in two-dimensional systems: From elliptical packings to tissues
18:00–18:30	Hong, Sungyeon (Australian National University) From Spatial Organisation to Information Flow: A Topological Perspective
19:00	<i>Dinner – 2-course meal</i>

Tuesday, 7 July 2026

Time	Session
09:00–10:00	Plenary 2: Edelsbrunner, Herbert (Institute of Science & Technology Austria) Order k: Delaunay and Brillouin
10:00–10:30	Skraba, Primoz (Queen Mary University London) Universality for Scale-Invariant Functionals – Theory
10:30–11:00	<i>Coffee break</i>
11:00–11:30	Bobrowski, Omer (Queen Mary University London) Universality for Scale-Invariant Functionals – Applications
11:30–12:00	Mémoli, Facundo (Ohio State University) Curvature Sets over Persistence Diagrams
12:00–14:00	<i>Lunch – 2-course meal</i>
14:00–15:00	Plenary 3: Salvalaglio, Marco (TU Dresden) Characterizing Distributions of Local Structures in Hyperuniform Patterns via Persistent Homology
15:00–15:30	Sperl, Matthias (Universität Köln / German-Aerospace-Center (DLR)) Signatures of the Jamming and Glass Transition
15:30–16:00	<i>Coffee break</i>
16:00–16:30	Wittmann, René (HHU Düsseldorf) Order and disorder in living systems
16:30–17:00	Guo, Yanzhi (Australian National University) Characterization of short- and medium-range order of condensed states via persistent homology
17:00–18:30	<i>Free discussion</i>
19:00	<i>Dinner – 2-course meal</i>

Wednesday, 8 July 2026

Time	Session
09:00–10:00	Plenary 4: Last, Günter (KIT Karlsruhe) Persistence of asymptotic variance under transport
10:00–10:30	Lachièze-Rey, Raphaël (INRIA Paris) Hyperuniform number variance bounds for Coulomb gases and Girko ensembles
10:30–11:00	<i>Coffee break</i>
11:00–11:30	Flimmel, Daniela (Charles University Prague) Wang type decorated lattice
11:30–12:00	Cramer Pedersen, Martin (University of Copenhagen) Probing the structure and dynamics of active systems using topological data analysis
12:00–12:30	Grabner, Peter (TU-Graz) Hyperuniformity on compact spaces
12:30–14:00	<i>Lunch – 2-course meal</i>
14:30–16:30	<i>Walking tour – Günzburg</i>
16:30–17:30	<i>Free</i>
18:00–20:00	<i>Dinner – 2-course meal</i>
20:00–22:00	<i>Poster session – wine and snacks</i>

Poster presenters

Presenter	Affiliation
Bair, Christian	German-Aerospace-Center (DLR)
Chebunin, Mikhail	Ulm University
Chernyshev, Vsevolod	Ulm University
Falk, Patrick	German-Aerospace-Center (DLR)
Fitz, Albert	German-Aerospace-Center (DLR)

Presenter	Affiliation
Frommer, Fabio	Universität Mainz
Gräfensteiner, Phillip	Ulm University
Hegde, Akshay Sateesh	National University of Singapore
Lotz, Luca	German-Aerospace-Center (DLR)
Nguyen, Tran Duc	Ulm University
Pabst, Dominik	FAU Erlangen–Nürnberg
Reinke, Chris	German-Aerospace-Center (DLR)
Rodriguez Vasquez, Rita	CUNEF Universidad, Madrid
Sukhanov, Ilja	Ulm University
Yim, Ka Man	University of Oxford

Thursday, 9 July 2026

Time	Session
09:00–10:00	Plenary 5: Online lecture: Ghosh, Subhro (National University of Singapore) Strongly correlated particle systems: a toolbox for machine intelligence
10:00–10:30	Bardenet, Rémi (University of Lille) Locating holes in silence: TDA applied to the zeros of short-time Fourier transforms
10:30–11:00	<i>Coffee break</i>
11:00–11:30	Räth, Christoph (German-Aerospace-Center (DLR)) Complex (dynamical) structures: Their higher order correlations, their traces in the Fourier domain and their prediction
11:30–12:00	Voigt, Axel (TU Dresden) Hyperuniformity and topological features of (active) two-phase systems
12:30–14:00	<i>Lunch – 2-course meal</i>

Time	Session
14:00–14:30	Jalowy, Jonas (Universität Paderborn) Box-Covariances of Hyperuniform Point Processes
14:30–15:00	Dallaporta, Sandrine (Université de Poitiers) Rate of convergence of empirical measures of hyperuniform point processes
15:00–15:30	<i>Coffee break</i>
15:30–16:00	Cammarota, Valentina (Sapienza Università di Roma) Two Point Function for Critical Points
16:00–16:30	Vidotto, Anna (Sapienza University of Rome) Testing for Non-Stationarity in Time-Dependent Spherical Random Fields
16:30–17:00	<i>Coffee break</i>
17:00–18:00	Plenary 6: Online lecture: Torquato, Salvatore (Princeton University) Disordered Ultradense Stealthy Hyperuniform Packings as a SAT–UNSAT Transition
18:00–18:30	<i>Discussion</i>
19:30	<i>Conference dinner – grill buffet</i>

Friday, 10 July 2026

Time	Session
09:00–10:00	Plenary 7: Blaszczyzyn, Bartłomiej (ENS / Inria Paris) From Generative Models to Hyperuniformity Estimation for Point Processes
10:00–10:30	Schulte, Matthias (TU Hamburg) Limit theorems for Boolean models
10:30–11:00	<i>Coffee break</i>

Time	Session
11:00–11:30	Romero, José Luis (Universität Wien) Statistics of spectrogram landmarks and zeros of random functions
11:30–12:00	Kabluchko, Zakhar (Universität Münster) Random Fields Arising from Divisibility Properties of Random Integers
12:00–12:30	Baralić, Đorđe (MISANU Belgrade) Some TDA ideas based on tilings and Tetris
12:30–12:40	<i>Closing remarks</i>
12:40–14:00	<i>Lunch – 2-course meal</i>

Lectures and Invited Talks

Monday, 6 July 2026

Plenary lecture

14:00–15:00

PLENARY LECTURE

Recent results on Anderson localization and photonic band gap properties in stealthy hyperuniform media

Paul J. Steinhardt*Princeton University*

Anderson localization in one dimension is the phenomenon where waves propagating through a disordered medium become exponentially localized in space, suppressing transport and turning the system into an effective insulator for that wave type, with the remarkable feature this occurs regardless of how weak the disorder is. This talk will describe how this textbook view must be modified for disordered stealthy hyperuniform one-dimensional media due to their possessing correlated disorder. We will also comment on gyromorphs, a recently proposed disordered medium in two and higher dimensions which has been proposed as an alternative to hyperuniformity with superior wave propagation properties.

Invited talk

15:00–15:30

INVITED TALK

Hyperuniformity in negative curvature

Mattias Bylehn*University of Vienna, Austria*

In Euclidean spaces, the large-scale fluctuations of translation invariant point processes can be examined geometrically and Fourier-analytically in an equivalent fashion, allowing one to characterize hyperuniformity of a point process in terms of the large-scale asymptotics of its number variance as well as the small-scale asymptotics of its structure factor. In the context of isometrically invariant point processes in hyperbolic spaces and regular trees (spaces of negative curvature where there is an analogue of classical Fourier analysis available) however, we find that this correspondence fails. Here number variances grow at least as fast as the volume of large balls and very few examples of "spectrally hyperuniform" processes are known, making the club of hyperuniform point processes a seemingly exclusive one. To arrive at our results will require some non-Euclidean Fourier analysis. No prior knowledge of this will be assumed.

Based on joint work with Michael Björklund (Chalmers)

Invited talk

16:00–16:30

INVITED TALK

Random bicontinuous structures: local curvature and domain size uniformity

Gerd E. Schröder-Turk*Murdoch University, Australia*

Do aperiodic counterparts of the triply-periodic minimal surfaces exist, that is, bicontinuous minimal surface geometries that divide space into two network-like components separated by a minimal surface, and how uniform are they? We will discuss numerical work that constructs sections of such surfaces from amorphous silicon network models and analyses their local structural uniformity in terms of curvature variations and domain-size variations. Such surfaces are relevant because of their occurrence in self-assembled soft-matter systems and because they represent interesting structural models for materials composed of network-like connected components with negatively curved interfaces. The question of how hyperuniformity relates to local uniformity in bicontinuous materials is fascinating, in part because interface curvatures in negatively curved systems cannot be uniform.

Invited talk

16:30–17:00

INVITED TALK

Quasicrystals with large rotational symmetries: Amorphous-like on small but ordered at large lengths scale

Alan Rodrigo Mendoza Sosa¹, Atahualpa S. Kraemer², Erdal C. Oğuz¹, Michael Schmiedeberg³

¹Key Laboratory of Soft Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing, 100190, China; ²Departamento de Física, Facultad de Ciencias, Universidad Nacional Autónoma de México, Ciudad Universitaria, 04510, Mexico City, Mexico; ³Soft Matter Theory group, Theoretical Physics: Lab for Emergent Phenomena, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

We study hyperuniformity in quasicrystals with large rotational symmetry. Quasicrystals are structures with long-ranged order but no translational symmetries. In principle, they can possess arbitrary rotational symmetry. On large length scales, quasicrystals are hyperuniform. Hyperuniform systems are characterized by anomalously suppressed long-wavelength (i.e., large-length-scale) density fluctuations compared to those found in ordinary gases and fluids as well as in amorphous solids. We show that the degree to which the large-scale fluctuations are suppressed reveals a new characteristic length-scale. Below this length the patterns behave like amorphous systems while only above this length the long-ranged order becomes important leading to hyperuniformity in all cases.

Invited talk

17:30–18:00

INVITED TALK

Lloyd optimisation in two-dimensional systems: From elliptical packings to tissues

Ana Suncana Smith*FAU Erlangen / RBI Zagreb, Germany*

In this presentation, I will discuss how cellular shape optimisation can influence density fluctuations. I will begin with random packings of ellipses and apply a generalised Lloyd algorithm to study how quasi-hyperuniformity emerges as a function of packing fraction and ellipticity. I will then draw a connection between these elliptical packings and biological tissues, showing that cell nuclei can act as generators of a Voronoi tessellation that accurately represents tissue structure. I will also demonstrate that nuclear positioning is governed by active processes that can be captured by a Lloyd-like functional. Finally, I will show that shape optimisation occurring on short timescales can have significant consequences for tissue development and topology over longer timescales.

Invited talk

18:00–18:30

INVITED TALK

From Spatial Organisation to Information Flow: A Topological Perspective

Sungyeon Hong*School of Cybernetics, The Australian National University*

Understanding how complex systems organise and transmit information across scales is a central challenge spanning physical and data-driven sciences. In this talk, I will present a unifying topological perspective on two seemingly distinct settings: geometry-driven spatial organisation and AI-mediated information flow.

First, I consider hyperuniform structures generated via Lloyd's algorithm, a Voronoi-based relaxation process in which local geometric interactions between neighbouring points drive the emergence of global order [1]. These systems exhibit suppressed large-scale density fluctuations and form predominantly hexagonal configurations interspersed with topological defects. By analysing the geometric and topological properties of these defects and their dynamics, we uncover scale-free correlations and locally favoured motifs that govern the self-organisation process, offering insight into universality in systems exhibiting collective behaviour [2,3].

Building on this structural perspective, I then turn to recent work on recursive information processing in generative AI systems. Using topological data analysis and clustering techniques, I examine semantic embedding trajectories arising from iterative text-to-image and image-to-text transformations. These trajectories reveal how different models and prompts shape the propagation and transformation of information across modalities, providing a framework for characterising information flow in complex, networked systems. This is joint work with Ben Swift (ANU) [4].

Together, these results highlight how topological methods can bridge spatial and semantic domains, offering a common language to study emergent structure and information dynamics in both physical and artificial systems.

References. [1] M. A. Klatt et al., *Nature Communications* **10**, 811 (2019). [2] S. Hong et al., *PNAS Nexus* **3**, pgae510 (2024). [3] S. Hong and M. Saadatfar, *Data-Driven Modelling* **1**, 1–11 (2025). [4] B. Swift and S. Hong, in *Proceedings of the 2025 IEEE International Conference on Systems, Man, and Cybernetics*, 664–667 (2025).

Tuesday, 7 July 2026

Plenary lecture

09:00–10:00

PLENARY LECTURE

Order k : Delaunay and Brillouin

Herbert Edelsbrunner*Institute of Science and Technology Austria*

The k -th Brillouin zone of a point A in a locally finite set consists of the locations at which A is the k -nearest point in the set. The first Brillouin zone is also known as the Voronoi domain of A . In the relatively straightforward case of a lattice, all Brillouin zones have the same volume, and their regions can be used to tile one another.

This talk is an attempt to review related solved and unsolved questions in discrete geometry, with an eye on what happens when the points are not quite as regularly spaced as in a lattice.

Invited talk

10:00–10:30

INVITED TALK

Universality for Scale-Invariant Functionals – Theory

Primož Skraba^{1,2}, Omer Bobrowski¹

¹*Queen Mary University of London*; ²*University of Ljubljana*

We present a general framework for proving that scale-invariant functionals of spatial point processes admit universal limiting distributions, meaning that the limit is independent of the underlying point-process distribution. Our primary motivation comes from topological data analysis (TDA), where we study random persistence diagrams generated by geometric filtrations. We show that, after a suitable scale-invariant transformation, the distribution of death/birth ratios converges to a universal limit that depends only on coarse parameters such as dimension and homological degree. The proof is based on a general universality principle for point-process functionals, which are of independent interest beyond TDA.

Invited talk

11:00–11:30

INVITED TALK

Universality for Scale-Invariant Functionals – Applications

Omer Bobrowski¹, Primoz Skraba^{1,2}

¹Queen Mary University of London, United Kingdom; ²University of Ljubljana

In this sequel talk, we explore the universality phenomenon from a practical and empirical perspective. For persistence diagrams, we present extensive experimental evidence indicating a stronger form of universality, observed across different dimensions, geometries, and classes of point processes, including hyperuniform processes. We then demonstrate how this phenomenon can be leveraged in applications, including topological inference, clustering, and intrinsic dimensionality estimation. These results highlight how universality can be used to design data-driven methods with minimal assumptions on the underlying distribution.

Invited talk

11:30–12:00

INVITED TALK

Curvature Sets over Persistence Diagrams

Facundo Mémoli*Rutgers University, United States of America*

We study a family of invariants of compact metric spaces that combines the curvature sets introduced by Gromov in the 1980s with persistent homology. One of our constructions is as follows: For fixed integers $k \geq 0$ and $n \geq 1$, we consider the degree- k Vietoris–Rips persistence diagrams of all subsets of cardinality at most n of a given metric space. We call these invariants persistence sets, and we call their measure-theoretic counterparts persistence measures. We establish that these invariants

- (1) can often be computed significantly more efficiently than the usual Vietoris–Rips persistence diagrams,
- (2) have strong discriminating power and, in many cases, capture information that is imperceptible to standard Vietoris–Rips persistence diagrams, and
- (3) enjoy stability properties.

We precisely characterize some of these invariants in the case of spheres and constant-curvature surfaces, using a generalization of Ptolemy’s inequality. We also identify a rich family of metric graphs for which one of the simplest persistence sets fully recovers the homotopy type of each graph, via split-metric decompositions.

Along the way, we prove several useful properties of Vietoris–Rips persistence diagrams. These yield a geometric algorithm for computing the Vietoris–Rips persistence diagram of a space X of cardinality $2k+2$ in quadratic time, as opposed to the much higher cost incurred by the usual algebraic algorithms based on matrix reduction.

This is joint work with Mario Gómez.

Plenary lecture

14:00–15:00

PLENARY LECTURE

Characterizing Distributions of Local Structures in Hyperuniform Patterns via Persistent Homology

Marco Salvalaglio*Technische Universität Dresden*

Hyperuniformity refers to the suppression of density fluctuations at large scales. Its classical definition uses information at the largest accessible scales, such as the scaling of the number variance with large sampling window sizes or the structure factor at small wave numbers. At the same time, hyperuniform (HU) patterns exhibit distinctive local arrangements that are not captured by these global measures. This presentation illustrates how local features in HU point clouds and fields can be characterized using persistent homology, along with key implications and applications.

Geometric and topological features across scales are encoded in persistence diagrams, and their similarities are quantified using Wasserstein distances. We find that varying HU characteristics leads to patterns with systematically different topological signatures. These features are preserved in subsets of such patterns, establishing a direct link between idealized infinite systems and experimentally or numerically accessible configurations. We further apply this framework to numerical solutions of the Cahn–Hilliard equation, a canonical model for generating HU scalar fields, discussing the characterization of self-similarity and scaling properties of its solutions at finite interface thicknesses.

Finally, concepts for the detection and inverse design of HU patterns leveraging persistent homology are outlined, showing that global HU properties can be inferred from distributions of local topological features in both point clouds and fields. The conclusions will highlight current challenges and perspectives, as well as potential further applications.

Invited talk

15:00–15:30

INVITED TALK

Signatures of the Jamming and Glass Transition

Matthias Sperl*German Aerospace Center DLR and University of Cologne, Germany*

Liquid-state theory shall be presented leading to the correlation functions identifying the liquid-glass transition within mode-coupling theory. Structural features, structural relaxation and structural arrest shall be explained briefly, before the theory is amended to granular systems and the glass transition is compared to the jamming transition where permanent contacts form. Higher-order transitions involving glass-glass transitions, endpoint singularities and additional jamming lines shall be presented as challenges to theory and numerical or experimental work alike.

A careful assessment is attempted to combine the glass and jamming transition with the concept of hyperuniformity.

Invited talk

16:00–16:30

INVITED TALK

Order and disorder in living systems

René Wittmann^{1,2}*¹Max Rubner-Institut, Germany; ²HHU Düsseldorf, Germany*

In the first part of my presentation, I introduce Active Ornstein-Uhlenbeck Particles (AOUPs), a simple model for self-propelled or swimming particles, and present analytical investigations of their response to position-dependent external fields, for example through density gradients in light-activated bacteria suspensions. In the second part, I discuss different ordering phenomena emerging in the early growth stage of bacterial colonies, focusing on their size-control mechanism, length distribution and the effect of substrate stiffness. Finally, I will highlight current research topics that could offer promising use cases for topological data analysis and tease the question of whether one can achieve that swimming bacteria self-assemble into hyperuniform patterns.

Invited talk

16:30–17:00

INVITED TALK

Characterization of short- and medium-range order of condensed states via persistent homology

Yanzhi Guo, Vanessa Robins

The Australian National University, Australia

Quantifying structural order in disordered and quasi-crystalline systems remains a fundamental challenge in materials science. This study employs persistent homology, a tool from topological data analysis, and quantities from discrete geometry to define bounds on length scales relevant to short- and medium-range order in condensed states. We provide a case study using point patterns generated via molecular dynamics (MD) simulations of particles interacting through an oscillating pair potential (OPP). By analyzing alpha-shape filtrations of these 3D point patterns, we derive persistence diagrams that encode topological features across scales. We establish a method to calculate the packing radius and covering radius from persistence data and use these to bound sample-relevant length scales for short-range order. Comparisons between simulated structures and idealized theoretical models reveal that persistence diagrams distinguish ordered phases by their topological signatures, with disordered systems exhibiting a broad range of local configurations in contrast to crystalline systems. This approach provides a parameter-free, system-agnostic framework to quantify structural correlations in condensed matter, that may offer insights into how atomic-scale topology influences macroscopic material properties.

Wednesday, 8 July 2026

Plenary lecture

09:00–10:00

PLENARY LECTURE

Persistence of asymptotic variance under transport

Günter Last*Karlsruhe Institute of Technology, Germany*

We consider invariant transports of stationary random measures on Euclidean space. Under natural mixing criteria, based on two-point Palm probabilities, we show that the asymptotic variance does not change. The mixing assumptions can be checked, for instance, by combining factorial moment expansion and stopping set techniques. In the second part of the lecture we will focus on hyperuniformity, that is, on a vanishing asymptotic variance. By constructing suitable transports from a hyperuniform source we are able to rigorously establish hyperuniformity for many point processes and random measures. In particular, we define a hyperuniformer that turns any ergodic point process with finite intensity into a hyperuniform process by randomizing each point within its cell of a fair partition.

The lecture is based on joint work with Michael Klatt, Luca Lotz and D. Yogeshwaran.

Invited talk

10:00–10:30

INVITED TALK

Hyperuniform number variance bounds for Coulomb gases and Girko ensembles

Raphaël Lachièze-Rey*INRIA, Paris, France*

Many models of interacting particle systems in a continuous medium, such as the eigenvalues of random matrices or Coulomb gases, seem to exhibit hyperuniformity: the variance of the number of points in a large ball is negligible compared to the expected number of points in the ball, as opposed to independent “Poisson” point systems, i.e., systems with no interaction, but only results with non-optimal rates exist to date.

Recent results on infinite stationary point processes show that hyperuniform variance rates obtained for smooth linear statistics transfer for free to number variance over balls, or other regular shapes, via an argument in Fourier space. This is convenient because smooth linear statistics are often easier to handle.

It turns out that a similar variance transfer principle works for large finite-size systems with asymptotic homogeneity: if a weak version of hyperuniformity is shown for the variance of smooth linear statistics, the rates obtained can be transferred to the variance of irregular linear statistics, such as the number variance on balls. A caveat is that it does not apply at all scales, and only a locally averaged version of the variance is available. We apply this principle to two- and three-dimensional Coulomb gases and Girko ensembles in random matrices, leveraging recent results on smooth linear statistics to give optimal hyperuniform rates. The work in Fourier space allows, in particular, finite Coulomb energy to be shown for the two-dimensional Coulomb gas.

Invited talk

11:00–11:30

INVITED TALK

Wang type decorated lattice

Daniela Flimmel*Charles University, Czech Republic (Czechia)*

We introduce a general class of point processes in \mathbb{R}^d obtained by decorating the lattice \mathbb{Z}^d with finitely many random templates selected according to a stationary vertex coloring. The construction unifies symbolic random fields on \mathbb{Z}^d with continuum point processes. Using this construction, one can efficiently generate large regions of disordered patterns while still maintaining asymptotic density fluctuations below the Poisson level. Conceptually, the approach follows the guiding idea of quasicrystals: ordered structures that lack periodicity.

Invited talk

11:30–12:00

INVITED TALK

Probing the structure and dynamics of active systems using topological data analysis

Martin Cramer Pedersen*University of Copenhagen, Denmark*

Active matter is a class of physical (often biological) systems characterized by the continuous conversion of energy into mechanical motion; resulting in the system being out of thermodynamical equilibrium. This property leads to a range of exciting phenomena including collective motion, exotic material properties, and phase transitions between complex states. Quintessential examples include epithelial cell monolayers, colonies of bacteria, and active swimmers. I will present some recent work on such systems, in which variations of topological data analysis have been key in understanding the dynamics and emerging structure.

Invited talk

12:00–12:30

INVITED TALK

Hyperuniformity on compact spaces

Peter Grabner*Graz University of Technology, Austria*

The concept of hyperuniformity had been introduced by S. Torquato and F. Stillinger to measure regularity of distributions of infinite particle systems in \mathbb{R}^d . An infinite particle system $X \subset \mathbb{R}^d$ is called hyperuniform, if the variance (with respect to the thermodynamic limit) of the number of points in a **large** ball is smaller than “usual”:

$$\mathbb{V}\#(X \cap B(\mathbf{x}, R)) = \mathcal{O}(R^{d-1}) \text{ for } R \rightarrow \infty.$$

Notice that this variance is of order R^d for Poisson point processes.

We generalise this concept to compact two point homogeneous spaces and the torus by considering sequences of **finite** point sets $(X_N)_N$ (with $\#X_N = N$). The phenomenon of a “smaller than usual” variance of the point counting function is then to be observed for geodesic balls with $N\text{vol}(B_R) \rightarrow \infty$ but $\text{vol}(B_R) \rightarrow 0$. We will discuss several examples of hyperuniform sequences of point sets.

Thursday, 9 July 2026

Plenary lecture

09:00–10:00

PLENARY LECTURE

Strongly correlated particle systems: a toolbox for machine intelligence

Subhro Ghosh*National University of Singapore*

The classical paradigm of randomness in the sciences is that of i.i.d. random variables, and going beyond i.i.d. is often considered a difficulty and a challenge to be overcome. In this talk, we will explore a new perspective, wherein strongly constrained random systems in fact help to understand fundamental problems in machine learning. In particular, we will discuss strongly correlated particle systems that are well-motivated from statistical and quantum physics, including determinantal probability measures. These will be used to shed important light on questions of fundamental interest in learning theory, focusing on applications to novel sampling techniques and advances in stochastic gradient descent.

The talk is based in part on work on Gaussian determinantal processes, negatively dependent coresets, determinantal minibatch sampling for stochastic gradient descent, and negative dependence as a toolbox for machine learning.

Invited talk

10:00–10:30

INVITED TALK

Locating holes in silence: TDA applied to the zeros of short-time Fourier transforms

Rémi Bardenet*CNRS, France*

Time-frequency analysis pertains to detecting and reconstructing information from noisy measurements of a physical quantity at discrete times. A cornerstone of this domain is the short-time Fourier transform (STFT), which is a collection of Fourier transforms applied to the original signal multiplied by a sliding window. Applied to a deterministic signal plus Gaussian noise, the STFT yields a random analytic function of the complex plane. While practitioners have historically focused on identifying level sets close to the maxima of this field, a recent paradigm shift has been to examine the point process formed by the zeros of the STFT. When the signal is pure Gaussian white noise, these zeros possess many interesting statistical properties, among which hyperuniformity and a fast-decaying hole probability. Locating holes in the zeros actually allows to detect, and reconstruct (i.e. denoise) the original signals. We will show a few results on the behaviour of these zeros, as well as how topological data analysis can be used to detect and localize signals in the time-frequency plane.

Invited talk

11:00–11:30

INVITED TALK

Complex (dynamical) structures: Their higher order correlations, their traces in the Fourier domain and their prediction

Christoph R ath*German Aerospace Center (DLR)*

A defining property of complex (dynamical) structures is the presence of higher-order correlations (HOC). We start by presenting methods for measuring the information contained in HOCs, focusing on Minkowski functionals and tensors. We outline how HOCs are represented in the Fourier domain. We introduce the method of surrogates and demonstrate how the type and strength of HOCs can be narrowed down by specially devised statistical tests involving surrogate data sets.

We further present reservoir computing (RC) as an efficient and interpretable AI method and its application to the classification of complex structures and the prediction of their dynamics. It turns out that prediction tasks are best performed if the only remaining tunable nonlinearity of the reservoir matches the degree of nonlinearity in the data. Possible further applications of the presented methodologies for hyperuniform data sets and materials science are briefly outlined.

Invited talk

11:30–12:00

INVITED TALK

Hyperuniformity and topological features of (active) two-phase systems

Rainer Backofen, Nadia Bihari Padhan, Axel Voigt

TU Dresden, Germany

We focus on patterns that emerge in two-phase systems, e.g., from spinodal decomposition and coarsening. In the simplest setting this can be modeled by the Cahn-Hilliard equation, which is known to produce disordered hyperuniform patterns. Modifications of this model, e.g. coupling with hydrodynamics, or incorporating active forces, have an affect on the emerging patterns. We aim to characterize the impact of these modifications on topological features of the patterns.

Invited talk

14:00–14:30

INVITED TALK

Box-Covariances of Hyperuniform Point Processes**Hanna Stange¹, Jonas Jalowy²***¹Münster University; ²Paderborn University, Germany*

When hyperuniform point processes are characterized by specific variance asymptotics of growing boxes, a natural question arises: What is the (relative) covariance between such two boxes? In this talk, we discuss a curious (non-)universal covariance structure of hyperuniform point processes depending on their class/exponent and identify a limiting Gaussian ‘coarse grained process’ counting the number of points in large boxes as a function of the position of the box. This talk is based on a joint work with Hanna Stange.

Invited talk

14:30–15:00

INVITED TALK

Rate of convergence of empirical measures of hyperuniform point processes

Sandrine Dallaporta*Université de Poitiers, France*

This talk is concerned with the empirical measure of a random point process in \mathbb{R}^d , such as the eigenvalues of a random matrix or a Coulomb gas. In several cases, this empirical measure converges towards a deterministic measure. In order to quantify the rate of convergence, we are interested in the p -Wasserstein distance between this random measure and its mean, particularly in dimension 2. We obtain a bound for this distance under some assumption on the p -th centered moment of the number of points in squares, which amounts to hyperuniformity when $p = 2$. In addition, hyperuniform determinantal point processes will satisfy the required assumptions for any $p \geq 1$.

This is a joint work with Raphaël Butez (Université de Lille) and David García-Zelada (Sorbonne Université).

Invited talk

15:30–16:00

INVITED TALK

Two Point Function for Critical Points

Valentina Cammarota*Sapienza University, Italy*

Random plane wave is conjectured to be a universal model for high-energy eigenfunctions of the Laplace operator on generic compact Riemannian manifolds. This is known to be true on average. In the present paper we discuss one of important geometric observable: critical points. We first compute one-point function for the critical point process, in particular we compute the expected number of critical points inside any open set. After that we compute the short-range asymptotic behaviour of the two-point function. This gives an unexpected result that the second factorial moment of the number of critical points in a small disc scales as the fourth power of the radius.

Invited talk

16:00–16:30

INVITED TALK

Testing for Non-Stationarity in Time-Dependent Spherical Random Fields

Anna Vidotto¹, Brendan K. Beare⁴, Alessia Caponera³, Claudio Durastanti¹, Massimo Franchi¹, Domenico Marinucci²

¹*Sapienza University of Rome, Italy;* ²*University of Rome Tor Vergata, Italy;*

³*LUISS Guido Carli, Rome, Italy;* ⁴*University of Sydney, Australia*

In this talk, we investigate, from a statistical point of view, time-dependent spherical random fields. After introducing the general framework, we focus on three main topics: Q1) Structural breaks exploration for general time dependent spherical random fields, introducing a test procedure under a broad range of alternatives, including deterministic trend, abrupt change, local stationarity, see [CMV26]; Q2) Parameter estimation of particular models, that are so-called stationary SPHARs, for which is possible to study estimation and prediction via either some classical OLS procedure or penalized LASSO procedure, see [CM21, CDV21]; Q3) Unit root type of non-stationarity in SPHARs, which is just a random walk type of non-stationarity. In this context, we present a procedure for estimation and inference on attractor and cointegrating spaces, see [BFV26]. Our results are then applied to NCEP data on global temperature: our estimates suggest that Climate Change does not simply affect global average temperatures, but also the nature of spatial fluctuations at different scales.

[CMV26] A. Caponera, D. Marinucci, A. Vidotto. Multi-Scale CUSUM Tests for Time Dependent Spherical Random Fields. *Journal of the American Statistical Association*, 1-20, 2026

[CM21] A. Caponera, D. Marinucci. Asymptotics for spherical functional autoregressions. *Annals of Statistics*, vol. 49, no. 1, pp. 346-369, 2021

[CDV21] A. Caponera, C. Durastanti, A. Vidotto. LASSO estimation for spherical autoregressive processes, *Stochastic Processes and their Applications*, vol. 137, 167-199, 2021

[BFV26] B.K. Beare, M. Franchi, A. Vidotto. Testing for Unit Roots in Spherical Isotropic Autoregressions, preprint, 2026+

Plenary lecture

17:00–18:00

PLENARY LECTURE

Disordered Ultradense Stealthy Hyperuniform Packings as a SAT–UNSAT Transition

Salvatore Torquato*Princeton University*

Stealthy hyperuniform point processes are those whose structure factor $S(k)$ vanishes over a finite exclusion region about the origin in reciprocal space (i.e., $S(k) = 0$ for $0 < k < K$) and therefore represent a strong form of hyperuniformity in which density fluctuations are anomalously suppressed from intermediate to infinite wavelengths [1]. The disordered variants have been shown to be the ground states of long-ranged pair potentials for the “stealthiness” parameter χ between zero and $1/2$. Sphere packings derived from disordered stealthy hyperuniform point configurations generated from numerical simulations have novel physical properties with advantages over their crystalline counterparts. However, the success rate to find allowable packing configurations with even moderate values of the packing fraction ϕ falls off rapidly with the number of particles within the fundamental cell.

Disordered ultradense stealthy packings are a recently introduced subclass of stealthy systems in which particles are subject to both the standard long-range constraints on density fluctuations and a short-range soft-core interparticle repulsive interaction [2]. At fixed χ , ϕ can be increased to its maximum value, ϕ_{\max} , beyond which the ground state ceases to exist, which can be viewed as a satisfiable–unsatisfiable (SAT–UNSAT) transition [3]. I will discuss these recent developments.

References. [1] S. Torquato, G. Zhang, and F. H. Stillinger, *Physical Review X* **5**, 021020 (2015). [2] J. Kim and S. Torquato, *The Journal of Chemical Physics* **163**, 024902 (2025). [3] S. Torquato and J. Kim, *Soft Matter* **21**, 4898–4907 (2025).

Friday, 10 July 2026

Plenary lecture

09:00–10:00

PLENARY LECTURE

From Generative Models to Hyperuniformity Estimation for Point Processes

Bartłomiej Błaszczyszyn

ENSAI / Inria, France

A single realization of a spatial process may, in principle, encode its full distribution through ergodicity—but how can this information be extracted from finite data?

I will present recent work on learning and generating point processes from a single sample using particle-based gradient descent and multiscale descriptors, and on estimating hyperuniformity through wavelet and spectral methods. These approaches emphasize the role of multiscale geometry in connecting stochastic modeling, statistical inference, and topological data analysis.

Invited talk

10:00–10:30

INVITED TALK

Limit theorems for Boolean models

Matthias Schulte*Hamburg University of Technology, Germany*

The union of the grains of a stationary Poisson process of compact convex sets in Euclidean space is called Boolean model and is a classical topic of stochastic geometry. One studies geometric functionals such as volume or Euler characteristic of Boolean models intersected with compact convex observation windows and is interested in the asymptotic behaviour for increasing observation windows. The goal of this talk is to present two different lines of research in this direction, namely Boolean models in hyperbolic space and discretised normal approximation of the Euler characteristic. One can construct Boolean models from isometry invariant Poisson processes of compact convex subsets of the hyperbolic space, which leads to new phenomena not observed in the Euclidean case. The Euler characteristic of a Boolean model in Euclidean space intersected with an observation window can be compared with a random variable following a discretised normal distribution in total variation distance, which strengthens existing limit theorems for the Euler characteristic.

This talk is based on joint works with Daniel Hug and Günter Last as well as with Arash Roostaei.

Invited talk

11:00–11:30

INVITED TALK

Statistics of spectrogram landmarks and zeros of random functions

José Luis Romero*University of Vienna, Austria*

The spectrogram portraits the temporal evolution of the frequency profile of a signal. While traditional signal processing methods focus on large values of the spectrogram, such as their maxima (“loud points”), in recent years, spectrogram zeros (“silent points”) have received significant attention as a set of alternative or supplementary landmarks to analyze signals impacted by noise. We contribute to this discussion by showing the following a) The silent points are hyperuniform while the loud points are not. This means that at large observation scales silent points enjoy significantly lower stochastic fluctuations than loud points, which supports the superiority of empirical statistics based on spectrogram zeros over those based on maxima. b) Spectrogram zeros and other point features can be computed reliably and efficiently from finitely given data. The corresponding algorithms are probably almost correct (small error in then Wasserstein metric). Joint work with Luis Alberto Escudero, Naomi Feldheim, Antti Haimi and Günther Koliander.

Invited talk

11:30–12:00

INVITED TALK

Random Fields Arising from Divisibility Properties of Random Integers

Zakhar Kabluchko, Alexander Marynych*University of Münster, Germany*

Let U_n and V_n be independent random variables uniformly distributed on $\{1, \dots, n\}$. It is classical that $\gcd(U_n, V_n)$ converges in distribution, as $n \rightarrow \infty$, to a non-degenerate limiting random variable. A random-field analogue of this result is also available: the field

$$\left(\gcd(U_n + u, V_n + v)\right)_{(u,v) \in \mathbb{Z}^2}$$

converges, as $n \rightarrow \infty$, to a non-trivial stationary random field on \mathbb{Z}^2 .

In this talk, we review this result and several related limit theorems on random fields arising from divisibility properties of random integers. The limiting processes typically have pure point spectrum supported on a dense subset of the torus, and are or may be conjectured to be hyperuniform. We then discuss a more general setting in which the pair (U_n, V_n) is replaced by polynomial expressions in U_n and V_n .

The talk is partially based on joint work with Alexander Marynych, <https://arxiv.org/abs/2311.05369>

Invited talk

12:00–12:30

INVITED TALK

Some TDA ideas based on tilings and Tetris

Đorđe Baralić*Mathematical Institute SANU, Serbia*

The Tetris game is based on tilings of a rectangular region by Tetris shapes. We introduce a class of simplicial complexes assigned to the tiling problem of a region by prescribed shapes, which is also a generalisation of the matching complexes of graphs. The topological and combinatorial properties of tiling complexes are interesting but not sufficiently explored.

In this contribution, we discuss ideas for using these tiling complexes in TDA. Inspired by the Tetris game, we develop new filtrations based on a series of embedded shapes or subgraphs, opening the way to implement the methods of persistence homology.

Posters

POSTER

Hyperuniformity Chain Rule: how to inherit hyperuniformity of a random scalar field?

Christian Bair

*Institut für Theoretische Physik II: Weiche Materie, Heinrich-Heine-Universität
Düsseldorf, Germany*

Hyperuniformity is a global property about long-range order that can be destroyed by local transformations, such as a segmentation based on threshold value. Here we investigate the possibility of a hyperuniform composition $g \circ F : x \mapsto g(F(x))$ of a function g with a scalar random field F . If F is hyperuniform, under what conditions on F or g does $g \circ F$ inherit this property? Conversely, can an appropriate choice of g convert a non-hyperuniform F into a hyperuniform field? We answer both questions by proving a *hyperuniformity chain rule*. For a broad class of stationary random fields F and functions g (the "garden-variety"), $g \circ F$ is non-hyperuniform. However, under a mixing condition on F , $g \circ F$ is hyperuniform for any g provided that $\langle |\tilde{g}(F(0))|^{2+\varepsilon} \rangle$ is finite for some $\varepsilon > 0$, with $\tilde{g}(x) = \int_0^x |g'(y)| dy$, if and only if F satisfies an explicit property, which we call *pluripotent*. As illustrations, we derive an even more explicit characterization of hyperuniformity of a function of a Gaussian random field, and we relate hyperuniformity of external potentials to the resulting number-densities, and show that segmentation via a threshold destroys hyperuniformity for the usual random field.

Joint work with Michael Andreas Klatt, Luca Lotz, Hartmut Löwen, and René Wittmann.

POSTER

Strong Sharpness of the Phase Transition in the Random Connection Model

Mikhail Chebunin

Ulm University, Germany

We study the random connection model (RCM) driven by a Poisson point process in a general spatial setting. In the subcritical regime, we investigate the light-tailed behavior of connected components and establish that the stationary marked RCM, encompassing the weight-dependent RCM as a special case, exhibits the strong sharp phase transition under natural assumptions. This is joint work with Günter Last (KIT).

POSTER

Detecting Functional Brain States in EEG Using Topological Features

Vsevolod Chernyshev*Ulm University, Germany*

This poster proposes a topological data analysis (TDA)-based feature engineering pipeline for unsupervised EEG segmentation, aiming to detect functional brain states without manual annotation. The authors integrate TDA features with the State-Detecting Algorithm (SDA) and introduce qSDA, a task-specific feature selection algorithm that filters high-dimensional topological descriptors according to their usefulness for stage detection. Experiments on Guhyasamaja Tantra meditation EEG recordings and the public sleep dataset show that topological features produce functional-stage boundaries comparable to, and often better than, traditional spectral features. The method remains robust under noisy data and performs poorly on shuffled epochs, suggesting that it captures meaningful temporal-spatial EEG structure rather than artifacts. Overall, the study presents TDA as a promising alternative or complement to spectral EEG features, with potential for more robust and interpretable functional-state detection.

POSTER

Long-Range Order Hidden in Short-Range Disorder: Challenging the Limits of Reliable CNN Classification

Patrick Falk¹, Christoph R ath^{2,3}, Arne Peter Raulf¹, Michael Andreas Klatt^{1,2,3}

¹German Aerospace Center (DLR), Institute for AI Safety and Security, Wilhelm-Runge-Str. 10, 89081 Ulm, Germany; ²German Aerospace Center (DLR), Institute of Frontier Materials on Earth and in Space, Functional, Granular, and Composite Materials, 51170 Cologne, Germany; ³Department of Physics, Ludwig-Maximilians-Universit t M nchen, Schellingstr. 4, 80799 Munich, Germany

Disordered hyperuniform materials combine short-range disorder with a hidden long-range order that results in unique physical properties. However, this combination of disorder and order turns out to be rather difficult to detect via classical convolutional neural networks (CNNs). Here, we probe and extend this limitation for more reliable machine learning predictions. To this end, we first implement and optimize such a vanilla CNN to classify grayscale images with edge cases of nearly hyperuniform disk packings. We then devise a light-weight Fourier-based network and demonstrate its superior prediction accuracy.

POSTER

Takens' way out of the valley of unpredictability?

**Albert Fitz, Joel Steinegger, Sebastian Bauer, Vincent Groß,
Matthias Sperl, Christoph R ath, Michael Klatt**

DLR, Germany

We model a mixture of chaotic signals by the weighted sum of two independent trajectories and compare the predictive performance of RC for the pure and mixed systems. The average score drops by an order of magnitude down into a 'valley of unpredictability'. Here we present work in progress that leverages Takens' embedding theorem to reconstruct a higher-dimensional state space from the mixed observation.

POSTER

(Non-)Hyperuniformity properties for second-order statistics of stationary point processes**Fabio Frommer, Martin Hanke***University of Mainz, Germany*

For stationary point processes on \mathbb{R}^d it is well-known that the expected value of the number of points N_R in the ball $B_R(0)$ scales with the volume of $B_R(0)$. However, this is not necessarily true for the variance of N_R , a point process is called *hyperuniform* if $\text{Var}(N_R) = o(R^d)$ this is e.g. the case for determinantal point processes with projection kernels or a simple perturbed lattice while for fast decaying Gibbs point processes it is known that $\text{Var}(N_R)/R^d \rightarrow c > 0$.

We investigate the variance of second order statistics, i.e. random variables of the type $F_R(\eta) = \sum_{x \neq y \in \eta \cap B_R(0)} f(x - y)$. We do so for pair interaction Gibbs point processes and determinantal point processes. We show instances where $\text{Var}(F_R)/R^d \rightarrow c = c(f) > 0$.

POSTER

Digital twins and hyperuniform sphere packings: Influence of 3D microstructure on effective tortuosity for applications in energy materials**Phillip Gräfensteiner¹, Patrick Falk², Michael A. Klatt^{2,3,4}, Volker Schmidt¹**

¹Ulm University, Institute of Stochastics, 89069 Ulm, Germany; ²German Aerospace Center (DLR), Institute for AI Safety and Security, 89081 Ulm, Germany; ³German Aerospace Center (DLR), Institute of Frontier Materials on Earth and in Space, Functional, Granular, and Composite Materials, 51170 Cologne, Germany; ⁴Department of Physics, Ludwig-Maximilians-Universität München, 80799 Munich, Germany

The performance of functional materials in energy applications is heavily determined by the morphology of their microstructure. For example, the spatial arrangement of individual active material particles in battery cathodes can significantly influence the efficiency of electronic or ionic diffusion within the cathode. This effect is often quantified by the effective tortuosity, which can be determined based on 3D image data by solving a diffusive transport problem. In order to expand the data base of available image data, stochastic modeling of the 3D microstructure is a vital tool that allows for the generation of virtual samples that are statistically similar to physical samples with respect to their morphology and functional response. Based on a thereby resulting data base of virtual microstructures, the relationship between geometric descriptors of the microstructures and macroscopic effective properties can be investigated by use of numerical simulations of physical transport phenomena. In addition to virtual particle assemblies generated by means of the stochastic microstructure model, various arrangements of spherical particles arising from hyperuniform and non-hyperuniform point patterns are studied with respect to their effective tortuosity.

POSTER

High local maxima of stationary smooth Gaussian fields

Akshay Hegde¹, Dmitry Belyaev²

¹National University of Singapore, Singapore; ²University of Oxford

Consider the point process (in \mathbb{R}^d) of local maxima of smooth Gaussian fields, with sufficient decay of correlation at infinity, above a level u . We show that this point process, rescaled appropriately, converges weakly to a Poisson point process in the limit $u \rightarrow \infty$. Our proof relies on the classical observation that simple point processes are characterised by avoidance probabilities (i.e. $\mathbb{P}(\eta(B) = 0)$ for a point process η and Borel set B). Then we approximate avoidance probability with the excursion probability, where the latter is well studied. Second main result is a quantified version of the Poisson convergence of high local maxima of the Bargmann-Fock field in \mathbb{R}^2 . We prove that, for Bargmann-Fock field in two dimensions, the total variation distance between a Poisson random variable and the number of local maxima of the field above a threshold u in an $R \times R$ box in \mathbb{R}^2 decays like $\exp(-\beta u^2)$, for some fixed $\beta > 0$. As an immediate consequence, when the level u is a function of R such that $u(R) \rightarrow \infty$ and $u(R)/\sqrt{\log R} \rightarrow 0$ as $R \rightarrow \infty$, we have a quantitative central limit theorem for the number of high local maxima. The proof is based on the Chen-Stein method for quantitative Poisson approximation. We produce a close coupling of a stationary smooth field and its Palm version, which might be of independent interest.

POSTER

Persistence of asymptotic variance under transport

Luca Lotz, Michael A. Klatt*DLR (German Aerospace Center), Germany*

We introduce p -uniformity to characterize the scaling of density fluctuations in spatial random systems in \mathbb{R}^d , ranging from hyperfluctuation to stealthy hyperuniformity. Our central theorem establishes sufficient conditions to preserve p -uniformity under transport. First, a finite $d + p$ -th moment of the transport distance allows for a Taylor expansion of the transport. The second condition controls the corresponding terms. We thus answer a previously stated open problem; indeed we extend it, since our result applies to a general p -uniform source in any dimension, and the source and transport may be dependent. As an application, we construct new classes of point processes that are isotropic and p -uniform with arbitrarily high p , and that can be simulated in linear time. We conclude with an outlook on a possible converse statement.

POSTER

Statistical Detection and Tensor-Based Pattern Discovery in EEG Signals

Duc Nguyen, Vsevolod Chernyshev, Evgeny Spodarev

Ulm University, Germany

We propose a general framework for multichannel EEG analysis based on spectral feature extraction and low-rank structure discovery. Multitaper methods are used to obtain stable time-frequency representations and bandpower features across channels, frequency bands, sessions, and experimental conditions. These features are then analysed with statistical and tensor-based methods to identify reproducible spatial, spectral, and temporal patterns in brain activity. The framework is designed to handle both labelled and unlabelled recordings, supporting hypothesis-driven comparison when state information is available and exploratory pattern discovery when it is not.

POSTER

Central limit theorems for Betti numbers in random simplicial complexes

Dominik Pabst*Friedrich Alexander University Erlangen-Nuremberg, Germany*

In topological data analysis, topological properties of data are analyzed via the Betti numbers of Čech and Vietoris–Rips complexes. In this work, we introduce a general probabilistic framework for random simplicial complexes that includes the Čech and Vietoris–Rips complexes, as well as the Boolean model, as special cases. Within this framework, we establish central limit theorems for Betti numbers and, more generally, for a broad class of functionals arising in random simplicial complexes. This approach provides new insight into the probabilistic structure underlying topological summaries in data analysis and identifies general conditions under which Gaussian fluctuations of Betti numbers arise.

POSTER

AI for Pattern Generation and Discovery

Chris Reinke^{1,2}, Mayalen Etcheverry², Pierre-Yves Oudeyer²

¹*DLR, Germany*; ²*Inria, France*

Can AI be used to automatically discover novel patterns exhibiting properties such as hyperuniformity? In our work, published at ICLR 2020, we explored this question through the automated discovery of diverse 2D spatial patterns for a cellular automaton inspired by the Game of Life. We combined intrinsically motivated goal-exploration processes (IMGEPs)—originally developed in developmental robotics—with deep variational autoencoders to drive open-ended exploration in a high-dimensional pattern space. This framework learns its own representation of “interesting” patterns and actively seeks out novel structures without relying on human-defined objectives. Our system uncovered a wide variety of spatially localized patterns and even outperformed methods pre-trained on curated databases of expert-identified configurations. This demonstrates that intrinsically motivated exploration can rival—and sometimes surpass—human-guided discovery pipelines. We aim to extend this methodology toward the targeted discovery of patterns with specific physical or topological properties, including hyperuniformity, topological invariants, and other mathematically structured features. Such capabilities could open new avenues in materials science, physics, and mathematics.

POSTER

Quantifying displacement: an urban expansion consequence via persistent homology

Rita Rodriguez Vazquez

CUNEF Universidad, Spain

Population displacement is a housing-related involuntary residential dislocation. It has become increasingly widespread in many cities, particularly in neighbourhoods undergoing rapid economic and demographic change, and measuring it is essential for assessing the social consequences of urban transformation and housing market pressures. Despite its relevance, quantifying displacement presents difficulties stemming from lack of replicability to other cities and time periods and from the fact that a long time-span must be analysed: displacement is a gradual process (leases end or conditions change at different times), impossible to capture in one data snapshot. We introduce a novel tool to overcome these difficulties. Using only publicly available address change data, we construct four cubical complexes which simultaneously incorporate geographical and temporal information of people moving, and then analyse them building on Topological Data Analysis tools. Finally, we demonstrate the potential of this method through a 20-year case study of Madrid, Spain. The results reveal its ability to capture population displacement and to identify the specific neighbourhoods and years affected—patterns that cannot be inferred from raw address change data.

This is joint work with Manuel Cuerno.

POSTER

Spectral optimal scale in TDA problems

Ilja Sukhanov¹, Djodrije Baralić², Oleksandr Leonov³, Lyudmila Polyakova³, Evgeny Spodarev¹

¹Universität Ulm, Germany; ²MISANU, Belgrade; ³Kharazin National University, Charkiw

Persistent homology is, by design, scale-agnostic: its central output, the persistence diagram, records topological features across all filtration scales simultaneously and thereby avoids committing to any single resolution. This is a genuine strength, and no scale-selection procedure can or should replace the full persistence diagram as a summary of multiscale structure. Nevertheless, a surprising number of problems in and around TDA reduce — explicitly or implicitly — to the choice of one filtration parameter, and doing so in a theoretically justified way remains a longstanding methodological gap. In our contribution, we try to fill it by studying the scale similarity matrices. We propose a general spectral principle for scale selection that applies to a very broad class of functionals on filtrations, far beyond homology ranks or simple face counts. Given a finite point cloud and a chosen filtration (Vietoris–Rips, Čech, α - or related complexes), we evaluate a (non)–monotonic functional across scales and assemble a nonnegative, symmetric similarity matrix whose entries encode cross-scale interactions of the complexes. The Perron–Frobenius eigenvalue–eigenvector pair of this matrix then identifies a small set of distinguished scales and, in particular, a spectrally optimal parameter at which the functional exhibits the most structurally significant behaviour in the context of the entire filtration, rather than at an isolated local extremum. This framework yields a unified, model-free way to detect topological phase transitions, to regularise noisy scale profiles, and to rank competing candidate scales in a filtration. We illustrate its use for a robust scale-selection in a variant of the MAPPER algorithm for topological data visualisation. The approach is theoretically justified by the connections between min/meet matrices and Markov chains.

POSTER

A Topological Stein Statistic for Goodness-of-Fit tests for Gibbs Point Processes

Ka Man Yim¹, Gesine Reinert¹, Omer Bobrowski²

¹University of Oxford, United Kingdom; ²Queen Mary University of London, United Kingdom

We propose a novel statistic for testing whether a given point configuration is sampled from a Gibbs point process (such as a Poisson point process). The Topological Stein Statistic combines a topological descriptor, such as Betti curves, with a Stein operator for Gibbs point processes. A Stein operator is a linear operator on functions which characterises probability distributions. In contrast with goodness-of-fit tests where the statistic is distribution agnostic, the Topological Stein Statistic encodes properties of the Gibbs point process in the statistic itself. We show examples where the Stein version of a topological statistic outperforms the normal topological statistic in goodness-of-fit tests for Gibbs processes. This talk features joint work with Gesine Reinert and Omer Bobrowski.

Order and Disorder in Random Geometries

Hyperuniformity and Topological Data Analysis

6–10 July 2026 • Schloss Reisensburg, Günzburg, Germany