SoCG'18

The 34th International Symposium on Computational Geometry

Contents

2018 June 11-14, Budapest.

Rényi Institute

CG Week Detailed Schedule

Please **check the homepage regularly** for up-to-date information.
`www.renyi.hu/conferences/socg18`

Lecture rooms:
GM: Gólyavár main lecture hall; **GS**: Gólyavár smaller room; **B172**: Building B room B172.

	DAY 1, June 11.	
8:00-9:00	Registration at **Gólyavár**	
9:00-9:10	Welcome	
9:10-10:30	**Session 1a. Room GM** *Chair: Michael Kerber*	**Session 1b. Room GS** *Chair: Dömötör Pálvölgyi*
	Herbert Edelsbrunner and Georg Osang: *The Multi-Cover Persistence of Euclidean Balls* (p.22)	**Sayan Bandyapadhyay, Santanu Bhowmick, Tanmay Inamdar and Kasturi Varadarajan:** *Capacitated Covering Problems in Geometric Spaces* (p.12)
	Magnus Bakke Botnan and Håvard Bakke Bjerkevik: *Computational Complexity of the Interleaving Distance* (p.15)	**Tanmay Inamdar and Kasturi Varadarajan:** *On Partial Covering For Geometric Set Systems* (p.27)
	Frédéric Chazal and Vincent Divol: *The Density of Expected Persistence Diagrams and its Kernel Based Estimation* (p.19)	**Édouard Bonnet and Panos Giannopoulos:** *Orthogonal Terrain Guarding is NP-Complete* (p.14)
	Mickaël Buchet and Emerson G. Escolar: *Realization of Indecomposable Persistence Modules of Arbitrarily Large Dimension* (p.15)	**Irina Kostitsyna, Bahram Kouhestani, Stefan Langerman and David Rappaport:** *An Optimal Algorithm to Compute the Inverse Beacon Attraction Region* (p.30)
10:30-11:00	**Coffee break**	
11:00-11:30	**Session 2. Room GM** *Chair: Michael Kerber.* **Best paper** by **Xavier Goaoc, Pavel Paták, Zuzana Patáková, Martin Tancer and Uli Wagner**: *Shellability is NP-Complete* (p.25)	
11:30-12:10	**Multimedia Sneak Previews** (Room **GM**)	
12:10-13:00	**YRF and Workshop Fast Forward** (Room **GM**)	
13:00-14:30	**Lunch break**	

DAY 1, June 11 cont'd.			
14:30-16:00	**YRF 1** (Room **GM**)	**Machine Learning** (Room **GS**)	**Fine Grained** (Room **B172**)
	14:30: Fugacci, Kerber, Manet: *Topology-aware Terrain Simplification* **14:45: Hoog, Kreveld, Meulemans, Verbeek, Wulms:** *Topological stability of kinetic k-centers* **15:00: Ophelders, Sonke, Speckmann, Verbeek:** *A KDS for Discrete Morse-Smale Complexes* **15:15: Kerber, Nigmetov:** *Spanners for Topological Summaries* **15:30: Corbet, Fugacci, Kerber, Landi, Wang:** *A Kernel for Multi-parameter Persistence* **15:45: Ölsböck:** *The Dynamic Wrap Complex*	**14:30-15:15: Bei Wang:** *Stratification Learning with Computational Topology: Overview, Challenges, and Opportunities* **15:15-16:00: Brittany Fasy:** *Road Network Analysis with Topological Data Analysis*	**14:30:** Opening words **14:35-15:25: Michał Pilipczuk:** *Parameterized algorithms for planar packing and covering problems using Voronoi diagrams* **15:30-15:50: Sándor Kisfaludi-Bak** Cube Wiring and its Applications
16:00-16:30	**Coffee break**		
16:30-18:00	**YRF 1** (Room **GM**)	**Machine Learning** (Room **GS**)	**Fine Grained** (Room **B172**) **starting at 16:20**
	16:30: Giunti, Chacholski, Landi: *Classification of filtered chain complexes* **16:45: Pritam, Boissonnat, Pareek:** *Strong Collapse for Persistence* **17:00: Schreiber, Maria:** *Morse Complexes for Zigzag Persistent Homology* **17:15: Krishnamoorthy, Saul, Wang:** *Stitch Fix for Mapper* **17:30: Schenfisch, Fasy:** *Curvature Estimates of Point Clouds as a Tool in Quantitative Prostate Cancer Classification*	**16:30-17:15: Melanie Schmidt:** *Practical Theory for Geometric Center Based Clustering* **17:15-18:00: Ioannis Z. Emiris:** *Randomized Projections for Geometric Search in High Dimension*	**16:20-17:10: Jean Cardinal:** *The geometry of 3SUM, k-SUM, and related problems* **17:15-17:35: Pritam Bhattacharya:** Approximation and Inapproximability of Guarding Polygons **17:40-18:00: Benjamin Burton:** Parameterised complexity for knots and manifolds – where to from here?
18:00-19:30	**Business Meeting** at Rényi Institute		
19:30-21:00	**DCG (Springer) reception** at Rényi Institute		

DAY 2, June 12.			
9:00-10:30	**YRF 2** (Room **GM**)	**Combinatorial Geom. 1** (Room **GS**)	**Computational Top. 1** (Room **B172**)
	9:00: Çağırıcı, Roy: *Maximum clique of disks in convex position* **9:15: Berg, Bodlaender, Kisfaludi-Bak, Marx, Zanden:** *An Algorithmic Framework for Geometric Intersection Graphs* **9:30: Damásdi:** *Conical partitions of point sets* **9:45: Keikha, Kerkhof, Kreveld, Kostitsyna, Löffler, Staals, Urhausen, Vermeulen, Wiratma:** *Convex Partial Transversals of Planar Regions* **10:00: Frankl:** *Large equilateral sets in subspaces of* ℓ_∞^n **10:15: Xue, Li, Rahul, Janardan:** *Searching for the closest-pair in a convex polygonal translate*	**9:00-9:30: Csaba Tóth:** *Exchange operations on noncrossing spanning trees* **9:30-10:00: Jean Cardinal:** *Topological Drawings of Complete Bipartite Graphs* **10:00-10:30: Radoslav Fulek:** $\mathbb{Z}_2$-*embeddings and Tournaments*	**9:00-9:25: Tamal Dey:** *Nerves can only kill, also serially!* **9:30-9:55: Ziga Virk:** *Persistence of geodesic spaces* **10:00-10:25: Sara Kalisnik:** *Learning algebraic varieties from samples*
10:30-11:00	**Coffee break**		
11:00-12:30	**YRF 2** (Room **GM**)	**Combinatorial Geom. 1** (Room **GS**)	**Computational Top. 1** (Room **B172**)
	11:00: Eder, Held: *Weighted Voronoi Diagrams in the L-inf Norm* **11:15: Jin, Huang:** *A technique for polygon inclusion problem* **11:30: Abdelkader:** *Delone Sets for Convex Bodies* **11:45: Buchin, Hulshof, Oláh:** $O(k)$*-robust spanners in one dimension* **12:00: Crombez, Fonseca, Gérard:** *Peeling Digital Potatoes* **12:15: Bhattacharya, Ghosh, Pal:** *Constant Approximation Algorithms for Guarding Simple Polygons using Edge and Perimeter Guards*	**11:00-11:30: Shakhar Smorodinsky:** k*-Conflict-Free Coloring of String Graphs* **11:30-12:00: Adrian Dumitrescu:** *Topological Drawings of Complete Bipartite Graphs* **12:00-12:30: Andrey Kupavskii:** *Tilings with noncongruent triangles*	**11:00-11:25: Lori Ziegelmeier:** *A complete characterization of the 1-dimensional intrinsic Cech persistence diagrams for metric graphs* **11:30-11:55: Yusu Wang:** *Gromov-Hausdorff and Interleaving Distances for Trees* **12:00-12:25: Mathijs Wintraecken:** *Triangulating stratified manifolds: a reach comparison theorem*
12:30-14:00	**Lunch break**		
14:00-15:00	**Session 3. Room GM. Invited talk** by **Jo Wood**: *Stories are not Just Words. Or How Visualization Helps us to Explain, Reason, Explore and Remember*		

DAY 2, June 12 cont'd.		
15:10-16:10	**Session 4a. Room GM** *Chair: Benjamin Raichel*	**Session 4b. Room GS** *Chair: Bei Wang*
	Ioannis Emiris and Ioannis Psarros: *Products of Euclidean Metrics and Applications to Proximity Questions among Curves* (p.23)	**Kristóf Huszár, Jonathan Spreer and Uli Wagner:** *On the Treewidth of Triangulated 3-Manifolds* (p.26)
	Marc Van Kreveld, Maarten Löffler and Lionov Wiratma: *On Optimal Polyline Simplification Using the Hausdorff and Fréchet Distance* (p.30)	**Jonathan Spreer and Stephan Tillmann:** *The Trisection Genus of Standard Simply Connected PL 4-Manifolds* (p.34)
	Olivier Devillers, Sylvain Lazard and William Lenhart: *3D Snap Rounding* (p.21)	**Jean-Daniel Boissonnat, Ramsay Dyer, Arijit Ghosh and Mathijs Wintraecken:** *Local Criteria for Triangulation of Manifolds* (p.13)
16:10-16:30	**Coffee break**	
16:30-17:50	**Session 5a. Room GM** *Chair: David Mount*	**Session 5b. Room GS** *Chair: Wouter Meulemans*
	Timothy M. Chan and Dimitrios Skrepetos: *Approximate Shortest Paths and Distance Oracles in Weighted Unit-Disk Graphs* (p.19)	**Zdenek Dvorak, Petr Hlineny and Bojan Mohar:** *Structure and Generation of Crossing-Critical Graphs* (p.22)
	Édouard Bonnet, Panos Giannopoulos, Eun Jung Kim, Paweł Rzążewski and Florian Sikora: *QPTAS and Subexponential Algorithm for Maximum Clique on Disk Graphs* (p.14)	**Fabian Klute and Martin Nöllenburg:** *Minimizing Crossings in Constrained Two-Sided Circular Graph Layouts* (p.29)
	A. Karim Abu-Affash, Paz Carmi, Anil Maheshwari, Pat Morin, Michiel Smid and Shakhar Smorodinsky: *Approximating Maximum Diameter-Bounded Subgraph in Unit Disk Graphs* (p.11)	**János Pach and Géza Tóth:** *A Crossing Lemma for Multigraphs* (p.33)
	Kevin Buchin, Jeff Phillips and Pingfan Tang: *Approximating the Distribution of the Median and other Robust Estimators on Uncertain Data* (p.15)	**Radoslav Fulek and Jan Kynčl:** *The $\mathbb{Z}_2$-Genus of Kuratowski Minors* (p.24)
19:30-22:00	**River Cruise & Dinner** at Port Akademia-3 (see p.36). Be there before 19:30!	

DAY 3, June 13.		
9:00-10:20	**Session 6a. Room GM** *Chair: Benjamin Raichel*	**Session 6b. Room GS** *Chair: Csaba Tóth*
	Roee David, Karthik C. S. and Bundit Laekhanukit: *On the Complexity of Closest Pair via Polar-Pair of Point-Sets* (p.20)	**Bruce Reed, Janos Pach and Yelena Yuditsky:** *Almost All String Graphs are Intersection Graphs of Plane Convex Sets* (p.33)
	Jie Xue, Yuan Li, Saladi Rahul and Ravi Janardan: *New Bounds on Range Closest-Pair Problems* (p.35)	**Chaya Keller and Shakhar Smorodinsky:** *From a $(p, 2)$-Theorem to a Tight (p, q)-Theorem* (p.28)
	Thijs Laarhoven: *Graph-Based Time-Space Trade-Offs for Approximate Near Neighbors* (p.30)	**Leonardo Martínez-Sandoval, Edgardo Roldán-Pensado and Natan Rubin:** *Further Consequences of the Colorful Helly Hypothesis* (p.31)
	Ryo Ashida and Kotaro Nakagawa: $\widetilde{O}(n^{1/3})$*-Space Algorithm for the Grid Graph Reachability Problem* (p.12)	**Balázs Keszegh:** *Coloring Intersection Hypergraphs of Pseudo-Disks* (p.29)
10:20-10:45	**Coffee break**	
10:45-11:45	**Session 7a. Room GM** *Chair: Siu-Wing Cheng*	**Session 7b. Room GS** *Chair: Jeff Erickson*
	Joseph O'Rourke: *Edge-Unfolding Nearly Flat Convex Caps* (p.32)	**Adam Brown and Bei Wang:** *Sheaf-Theoretic Stratification Learning* (p.15)
	Malte Milatz: *Random Walks on Polytopes of Constant Corank* (p.31)	**Kevin Knudson and Bei Wang:** *Discrete Stratified Morse Theory: A User's Guide* (p.29)
	Herbert Edelsbrunner, Žiga Virk and Hubert Wagner: *Smallest Enclosing Spheres and Chernoff Points in Bregman Geometry* (p.22)	**Tamal Dey, Jiayuan Wang and Yusu Wang:** *Graph Reconstruction by Discrete Morse Theory* (p.21)
11:45-12:00	**Short break**	
12:00-13:00	**Session 8a. Room GM** *Chair: Bettina Speckmann*	**Session 8b. Room GS** *Chair: Dömötör Pálvölgyi*
	Timothy M. Chan: *Tree Drawings Revisited* (p.18)	**Tamal Dey and Cheng Xin:** *Computing Bottleneck Distance for 2-D Interval Decomposable Modules* (p.22)
	Arthur van Goethem and Kevin Verbeek: *Optimal Morphs of Planar Orthogonal Drawings* (p.25)	**Wai Ming Tai and Jeff Phillips:** *Near-Optimal Coresets of Kernel Density Estimates* (p.34)
	Yifei Jin, Jian Li and Wei Zhan: *Odd Yao-Yao Graphs may not be Spanners* (p.28)	**Bruno Jartoux and Nabil H. Mustafa:** *Optimality of Geometric Local Search* (p.27)
13:00-14:30	**Lunch break**	

DAY 3, June 13 cont'd.			
14:30-15:30	**Session 9. Room GM. Invited talk** by **András Máthé**: *Circle squaring and other combinatorial problems in geometric measure theory*		
15:30-16:45	**YRF 3** (Room **GM**)	**Educational Forum** (Room **GS**)	**Computational Top. 2** (Room **B172**)
	15:30: Held, Lorenzo: *Spiral-Like Paths on Triangulated Terrains* **15:45: Vass, Tapolcai:** *Enumerating Maximal Regional Failures of Backbone Communication Networks in Near Linear Parametric Time* **16:00: Löffler, Beck, Blum, Kryven, Zink:** *NP-completeness of Planar Steiner Orientation* **16:15: Keller, Perles:** *Blockers for Simple Hamiltonian Paths in Convex Geometric Graphs of Odd Order* **16:30: Asinowski, Barequet, Zheng:** *On d-D Polycubes with Small Perimeter Defect*	**15:30-15:50: Sándor Fekete:** *IDEA instructions: Visualizing algorithms without words* **15:50-16:10: Brittany Fasy:** *Teaching Computational (Geometry and) Topology* **16:10-16:30: Jisu Kim:** *R package TDA for Topological Data Analysis* **16:30-16:50: Efi Fogel:** *Teaching with CGAL Arrangements*	**15:30-16:00: Omer Bobrowski:** *Homological percolation - the formation of large cycles* **16:05-16:35: Anthea Monod:** *Statistical Inference for Persistent Homology via Rank Functions*
16:45-17:15	**Coffee break**		
17:15-18:30	**Combinatorial Geometry 2** (Room **GM**)	**Educational Forum** (Room **GS**)	**Computational Top. 2** (Room **B172**)
	17:15-17:35: Bartosz Walczak: *Towards double-logarithmic upper bounds on the chromatic number of triangle-free geometric intersection graphs* **17:35-17:55: Nabil Mustafa:** *Local search: combinatorial, metric and Euclidean* **18:00- :** Open ended open problem session	**17:15-17:30: Dave Millman and Joe Mitchell:** *Overview of CG/CT courses taught worldwide* **17:30-18:30:** Panel discussion: *Franz Aurenhammer, Erin Chambers, Dan Halperin, David Mount, Joe O'Rourke*	**17:15-17:45: Primoz Skraba:** *Random Structures, Persistence, and Stability* **17:50-18:20:** Discussion

DAY 4, June 14.		
9:20-10:20	**Session 10a. Room GM** *Chair: Luis Barba*	**Session 10b. Room GS** *Chair: Jeff Erickson*
	Timothy M. Chan and Konstantinos Tsakalidis: *Dynamic Planar Orthogonal Point Location in Sublogarithmic Time* (p.19)	**Anastasios Sidiropoulos, Kritika Singhal and Vijay Sridhar:** *Fractal Dimension and Lower Bounds for Geometric Problems* (p.34)
	Pankaj Agarwal, Lars Arge and Frank Staals: *Improved Dynamic Geodesic Nearest Neighbor Searching in a Simple Polygon* (p.12)	**Michael Elkin and Ofer Neiman:** *Near Isometric Terminal Embeddings for Doubling Metrics* (p.23)
	Sang Won Bae, Sergio Cabello, Otfried Cheong, Yoonsung Choi, Fabian Stehn and Sang Duk Yoon: *The Reverse Kakeya Problem* (p.12)	**Timothy Carpenter, Anastasios Sidiropoulos, Daniel Lokshtanov, Fedor Fomin and Saket Saurabh:** *Algorithms for Low-Distortion Embeddings into Arbitrary 1-Dimensional Spaces* (p.17)
10:20-10:45	**Coffee break**	
10:45-11:45	**Session 11a. Room GM** *Chair: Marc van Kreveld*	**Session 11b. Room GS** *Chair: Birgit Vogtenhuber*
	Eunjin Oh and Hee-Kap Ahn: *Point Location in Dynamic Planar Subdivisions* (p.32)	**Oliver Roche-Newton:** *An Improved Bound for the Size of the Set $A/A + A$* (p.34)
	Ivor Hoog V.D., Elena Khramtcova and Maarten Löffler: *Dynamic Smooth Compressed Quadtrees* (p.26)	**Boris Bukh, Xavier Goaoc, Alfredo Hubard and Matthew Trager:** *Consistent Sets of Lines with No Colorful Incidence* (p.16)
	Eunjin Oh and Hee-Kap Ahn: *Approximate Range Queries for Clustering* (p.32)	**Jean Cardinal, Timothy M. Chan, John Iacono, Stefan Langerman and Aurélien Ooms:** *Subquadratic Encodings for Point Configurations* (p.17)
11:45-12:00	**Short break**	
12:00-13:00	**Session 12a. Room GM** *Chair: Siu-Wing Cheng*	**Session 12b. Room GS** *Chair: Bettina Speckmann*
	Haitao Wang and Jingru Zhang: *An $O(n \log n)$-Time Algorithm for the k-Center Problem in Trees* (p.35)	**Andreas Haas:** *Solving Large-Scale Minimum-Weight Triangulation Instances to Provable Optimality* (p.26)
	Ahmad Biniaz, Prosenjit Bose, Paz Carmi, Anil Maheshwari, Ian Munro and Michiel Smid: *Faster Algorithms for some Optimization Problems on Collinear Points* (p.13)	**Jérémie Chalopin, Victor Chepoi, Feodor F. Dragan, Guillaume Ducoffe, Abdulhakeem Mohammed and Yann Vaxès:** *Fast Approximation and Exact Computation of Negative Curvature Parameters of Graphs* (p.18)
	Sharath Raghvendra: *Optimal Analysis of an Online Algorithm for the Bipartite Matching Problem on a Line* (p.33)	**Ludovic Calès, Apostolos Chalkis, Ioannis Emiris and Vissarion Fisikopoulos:** *Practical Volume Computation of Structured Convex Bodies, and an Application to Modeling Portfolio Dependencies and Financial Crises* (p.16)

	DAY 4, June 14 cont'd.	
13:00-14:30	**Lunch break**	
14:30-15:30	**Session 13a. Room GM** *Chair: Luis Barba*	**Session 13b. Room GS** *Chair: Csaba Tóth*
	Chih-Hung Liu: *A Nearly Optimal Algorithm for the Geodesic Voronoi Diagram of Points in a Simple Polygon* (p.31)	**Radoslav Fulek and Jan Kynčl:** *Hanani–Tutte for Approximating Maps of Graphs* (p.24)
	Kolja Junginger and Evanthia Papadopoulou: *Deletion in Abstract Voronoi Diagrams in Expected Linear Time* (p.28)	**Éric Colin de Verdière, Thomas Magnard and Bojan Mohar:** *Embedding Graphs into Two-Dimensional Simplicial Complexes* (p.20)
	Ahmed Abdelkader, Chandrajit Bajaj, Mohamed Ebeida, Ahmed Mahmoud, Scott Mitchell, John Owens and Ahmad Rushdi: *Sampling Conditions for Conforming Voronoi Meshing by the VoroCrust Algorithm* (p.11)	**Joshua Grochow and Jamie Tucker-Foltz:** *Computational Topology and the Unique Games Conjecture* (p.25)
15:30-15:50	**Coffee break**	
15:50-16:50	**Session 14a. Room GM** *Chair: David Mount*	**Session 14b. Room GS** *Chair: Michael Kerber*
	Erik D. Demaine, Sándor Fekete, Phillip Keldenich, Henk Meijer and Christian Scheffer: *Coordinated Motion Planning: Reconfiguring a Swarm of Labeled Robots with Bounded Stretch* (p.20)	**Michal Adamaszek, Henry Adams, Ellen Gasparovic, Maria Gommel, Emilie Purvine, Radmila Sazdanovic, Bei Wang, Yusu Wang and Lori Ziegelmeier:** *Vietoris-Rips and Cech Complexes of Metric Gluings* (p.11)
	Victor Milenkovic, Elisha Sacks and Nabeel Butt: *Table Based Detection of Degenerate Predicates in Free Space Construction* (p.32)	**Jean-Daniel Boissonnat, André Lieutier and Mathijs Wintraecken:** *The Reach, Metric Distortion, Geodesic Convexity and the Variation of Tangent Spaces* (p.14)
	Stefan Felsner, Linda Kleist, Torsten Mütze and Leon Sering: *Rainbow Cycles in Flip Graphs* (p.24)	**Benjamin A. Burton:** *The HOMFLY-PT Polynomial is Fixed-Parameter Tractable* (p.16)
16:50-17:00	**Best Student Presentation Award**	

60th Birthday Celebrations for Herbert Edelsbrunner, Raimund Seidel and Emo Welzl

Organizers: Tamal Dey, Jeff Erickson, Uli Wagner.

June 15, 2018 at the **Rényi Institute.**

9:00–9:05	*Opening remarks*
9:10–9:40	**Hermann Maurer** (video/scribe presentation), Graz Univ. of Technology
9:45–10:15	**Micha Sharir,** Tel Aviv Univ.
10:20–10:50	Coffee break
10:50–11:20	**Jack Snoeyink,** UNC Chapel Hill
11:25–11:55	**János Pach,** EPFL and Rényi Institute
12:00–1:30	Lunch

For Herbert Edelsbrunner

13:30–13:55	**Tiow Seng Tan,** National Univ. Singapore
14:00–14:25	**Dmitriy Morozov,** Lawrence Berkeley National Lab

For Raimund Seidel

14:30–14:55	**Nina Amenta,** UC Davis
15:00–15:25	**David Kirkpatrick,** UBC

For Emo Welzl

15:30–15:55	**Bernd Gärtner,** ETH Zürich
16:00–16:25	**József Solymosi,** University of British Columbia
16:30–16:55	Coffee break
17:00–17:45	Remarks by three honorees
17:45–18:00	Final remarks

SoCG 2018 Abstracts

Ahmed Abdelkader, Chandrajit Bajaj, Mohamed Ebeida, Ahmed Mahmoud, Scott Mitchell, John Owens and Ahmad Rushdi: *Sampling Conditions for Conforming Voronoi Meshing by the VoroCrust Algorithm*

We study the problem of decomposing a volume with a smooth boundary into a collection of Voronoi cells. Unlike the dual problem of conforming Delaunay meshing, a principled solution to this problem for generic smooth surfaces remained elusive. VoroCrust leverages ideas from weighted α-shapes and the power crust algorithm to produce unweighted Voronoi cells conforming to the surface, yielding the first provably-correct algorithm for this problem. Given a κ-sparse ϵ-sample, we work with the balls of radius δ times the local feature size centered at each sample. The corners of the union of these balls on both sides of the surface are the Voronoi sites and the interface of their cells is a watertight surface reconstruction embedded in the dual shape of the union of balls. With the surface protected, the enclosed volume can be further decomposed by generating more sites inside it. Compared to clipping-based algorithms, VoroCrust cells are full Voronoi cells, with convexity and fatness guarantees. Compared to the power crust algorithm, VoroCrust cells are not filtered, are unweighted, and offer greater flexibility in meshing the enclosed volume by either structured or randomly genenerated samples.

A. Karim Abu-Affash, Paz Carmi, Anil Maheshwari, Pat Morin, Michiel Smid and Shakhar Smorodinsky: *Approximating Maximum Diameter-Bounded Subgraph in Unit Disk Graphs*

We consider a well studied generalization of the maximum clique problem which is defined as follows. Given a graph G on n vertices and a fixed parameter $d \geq 1$, in the maximum diameter-bounded subgraph problem (MaxDBS for short), the goal is find a (vertex) maximum subgraph of G of diameter at most d. For $d = 1$, this problem is equivalent to the maximum clique problem and thus it is NP-hard to approximate it within a factor $n^{1-\epsilon}$, for any $\epsilon > 0$. Moreover, it is known that, for any $d \geq 2$, it is NP-hard to approximate MaxDBS within a factor $n^{1/2-\epsilon}$, for any $\epsilon > 0$.

In this paper we focus on MaxDBS for the class of unit disk graphs. We provide a polynomial-time constant-factor approximation algorithm for the problem. The approximation ratio of our algorithm does not depend on the diameter d. Even though the algorithm itself is simple, its analysis is rather involved. We combine tools from the theory of hypergraphs with bounded VC-dimension, k-quasi planar graphs, fractional Helly theorems and several geometric properties of unit disk graphs.

Michal Adamaszek, Henry Adams, Ellen Gasparovic, Maria Gommel, Emilie Purvine, Radmila Sazdanovic, Bei Wang, Yusu Wang and Lori Ziegelmeier: *Vietoris-Rips and Cech Complexes of Metric Gluings*

We study Vietoris-Rips and Cech complexes of metric wedge sums and metric gluings. We show that the Vietoris-Rips (resp. Cech) complex of a wedge sum, equipped with a natural metric, is homotopy equivalent to the wedge sum of the

Vietoris-Rips (resp. Cech) complexes. We also provide generalizations for certain metric gluings, i.e., when two metric spaces are glued together along a common isometric subset. As our main example, we deduce the homotopy type of the Vietoris-Rips complex of two metric graphs glued together along a sufficiently short path. As a result, we can describe the persistent homology, in all homological dimensions, of the Vietoris-Rips complexes of a wide class of metric graphs.

Pankaj Agarwal, Lars Arge and Frank Staals: *Improved Dynamic Geodesic Nearest Neighbor Searching in a Simple Polygon*

We present an efficient dynamic data structure that supports geodesic nearest neighbor queries for a set S of point sites in a static simple polygon P. Our data structure allows us to insert a new site in S, delete a site from S, and ask for the site in S closest to an arbitrary query point $q \in P$. All distances are measured using the geodesic distance, that is, the length of the shortest path that is completely contained in P. Our data structure achieves polylogarithmic update and query times, and uses $O(n \log^3 n \log m + m)$ space, where n is the number of sites in S and m is the number of vertices in P. The crucial ingredient for our data structure is an implicit representation of a vertical shallow cutting of the geodesic distance functions. We show that such an implicit representation exists, and that we can compute it efficiently.

Ryo Ashida and Kotaro Nakagawa: *$\widetilde{O}(n^{1/3})$-Space Algorithm for the Grid Graph Reachability Problem*

The directed graph reachability problem takes as input an n-vertex directed graph $G = (V, E)$, and two distinguished vertices s and t. The problem is to determine whether there exists a path from s to t in G. This is a canonical complete problem for class NL. Asano et al. proposed an $\widetilde{O}(\sqrt{n})$ space and polynomial time algorithm for the directed grid and planar graph reachability problem. The main result of this paper is to show that the directed graph reachability problem restricted to grid graphs can be solved in polynomial time using only $\widetilde{O}(n^{1/3})$ space.

Sang Won Bae, Sergio Cabello, Otfried Cheong, Yoonsung Choi, Fabian Stehn and Sang Duk Yoon: *The Reverse Kakeya Problem*

We prove a generalization of Pal's 1921 conjecture that if a convex shape P can be placed in any orientation inside a convex shape Q in the plane, then P can also be turned continuously through 360° inside Q. We also prove a lower bound of $\Omega(mn^2)$ on the number of combinatorially distinct maximal placements of a convex m-gon P in a convex n-gon Q. This matches the upper bound proven by Agarwal, Amenta, and Sharir in 1998.

Sayan Bandyapadhyay, Santanu Bhowmick, Tanmay Inamdar and Kasturi Varadarajan: *Capacitated Covering Problems in Geometric Spaces*

In this article, we consider the following capacitated covering problem. We are given a set P of n points and a set B of balls from some metric space, and a positive integer U that represents the capacity of each of the balls in B. We would like to compute a subset $B_0 \subset B$ of balls and assign each point in P to some ball in B_0

that contains it, such that the number of points assigned to any ball is at most U. The objective function that we would like to minimize is the cardinality of B_0. We consider this problem in arbitrary metric spaces as well as Euclidean spaces of constant dimension. In the metric setting, even the uncapacitated version of the problem is hard to approximate to within a logarithmic factor. In the Euclidean setting, the best known approximation guarantee in dimensions 3 and higher is logarithmic. Thus we focus on obtaining "bi-criteria" approximations. In particular, we are allowed to expand the balls in our solution by some factor, but optimal solutions do not have that flexibility. Our main result is that allowing constant factor expansion of the input balls suffices to obtain constant approximations for these problems. In fact, in the Euclidean setting, only $(1+\varepsilon)$ factor expansion is sufficient for any $\varepsilon > 0$, with the approximation factor being a polynomial in $1/\varepsilon$. We obtain these results using a unified scheme for rounding the natural LP relaxation; this scheme may be useful for other capacitated covering problems. We also complement these bi-criteria approximations by obtaining hardness of approximation results that shed light on our understanding of these problems.

Ahmad Biniaz, Prosenjit Bose, Paz Carmi, Anil Maheshwari, Ian Munro and Michiel Smid: *Faster Algorithms for some Optimization Problems on Collinear Points*

We propose faster algorithms for the following three optimization problems on n collinear points, i.e., points in dimension one. The first two problems are known to be NP-hard in higher dimensions. 1- Maximizing total area of disjoint disks: In this problem the goal is to maximize the total area of nonoverlapping disks centered at the points. Acharyya, De, and Nandy (2017) presented an $O(n^2)$-time algorithm for this problem. We present an optimal $\Theta(n)$-time algorithm. 2- Minimizing sum of the radii of client-server coverage: The n points are partitioned into two sets, namely clients and servers. The goal is to minimize the sum of the radii of disks centered at servers such that every client is in some disk, i.e., in the coverage range of some server. Lev-Tov and Peleg (2005) presented an $O(n^3)$-time algorithm for this problem. We present an $O(n^2)$-time algorithm, thereby improving the running time by a factor of $\Theta(n)$. 3- Minimizing total area of point-interval coverage: The n input points belong to an interval I. The goal is to find a set of n disks of minimum total area, covering I, such that every disk contains at least one input point, and every input point is assigned to exactly one disk containing it. We present an algorithm that solves this problem in $O(n^2)$ time.

Jean-Daniel Boissonnat, Ramsay Dyer, Arijit Ghosh and Mathijs Wintraecken: *Local Criteria for Triangulation of Manifolds*

We present criteria for establishing a triangulation of a manifold. Given a manifold M, a simplicial complex A, and a map H from the underlying space of A to M, our criteria are presented in local coordinate charts for M, and ensure that H is a homeomorphism. These criteria do not require a differentiable structure, or even an explicit metric on M. No Delaunay property of A is assumed. The result provides a triangulation guarantee for algorithms that construct a simplicial complex by working in local coordinate patches. Because the criteria are easily checked algorithmically, they are expected to be of general use.

Jean-Daniel Boissonnat, André Lieutier and Mathijs Wintraecken: *The Reach, Metric Distortion, Geodesic Convexity and the Variation of Tangent Spaces*

In this paper we discuss three results. The first two concern general sets of positive reach: We first characterize the reach by means of a bound on the metric distortion between the distance in the ambient Euclidean space and the set of positive reach. Secondly, we prove that the intersection of a ball with radius less than the reach with the set is geodesically convex, meaning that the shortest path between any two points in the intersection lies itself in the intersection. For our third result we focus on manifolds with positive reach and give a bound on the angle between tangent spaces at two different points in terms of the distance between the points and the reach.

Édouard Bonnet and Panos Giannopoulos: *Orthogonal Terrain Guarding is NP-Complete*

A terrain is an x-monotone polygonal curve, i.e., successive vertices have increasing x-coordinates. Terrain Guarding can be seen as a special case of the famous art gallery problem where one has to place at most k guards on a terrain made of n vertices in order to fully see it. In 2010, King and Krohn showed that Terrain Guarding is NP-complete [SODA '10, SIAM J. Comput. '11] thereby solving a long-standing open question. They observe that their proof does not settle the complexity of Orthogonal Terrain Guarding where the terrain only consists of horizontal or vertical segments; those terrains are called rectilinear or orthogonal. Recently, Ashok et al. [SoCG'17] presented an FPT algorithm running in time $k^{O(k)}n^{O(1)}$ for Dominating Set in the visibility graphs of rectilinear terrains without 180-degree vertices. They ask if Orthogonal Terrain Guarding is in P or NP-hard. In the same paper, they give a subexponential-time algorithm running in $n^{O(\sqrt{n})}$ (actually even $n^{O(\sqrt{k})}$) for the general Terrain Guarding and notice that the hardness proof of King and Krohn only disproves a running time $2^{o(n^{1/4})}$ under the ETH. Hence, there is a significant gap between their $2^{O(n^{1/2}\log n)}$-algorithm and the no $2^{o(n^{1/4})}$ ETH-hardness implied by King and Krohn's result. In this paper, we answer those two remaining questions. We adapt the gadgets of King and Krohn to rectilinear terrains in order to prove that even Orthogonal Terrain Guarding is NP-complete. Then, we show how their reduction from Planar 3-SAT (as well as our adaptation for rectilinear terrains) can actually be made linear (instead of quadratic).

Édouard Bonnet, Panos Giannopoulos, Eun Jung Kim, Paweł Rzążewski and Florian Sikora: *QPTAS and Subexponential Algorithm for Maximum Clique on Disk Graphs*

A (unit) disk graph is the intersection graph of closed (unit) disks in the plane. Almost three decades ago, an elegant polynomial-time algorithm was found for Maximum Clique on unit disk graphs [Clark, Colbourn, Johnson; Discrete Mathematics '90]. Since then, it has been an intriguing open question whether or not this tractability can be extended to the more general disk graphs. We show the rather surprising result that a disjoint union of cycles is the complement of a disk graph if and only if at most one of those cycles is of odd length. From that, we derive the first QPTAS and subexponential algorithm for Maximum Clique on disk graphs. In stark contrast, Maximum Clique in the intersection graph of ellipses or triangles is very unlikely to have such algorithms.

Magnus Bakke Botnan and Håvard Bakke Bjerkevik: *Computational Complexity of the Interleaving Distance*
The interleaving distance is arguably the most prominent distance measure in topological data analysis. In this paper, we provide bounds on the computational complexity of determining the interleaving distance in several settings. We show that the interleaving distance is NP-hard to compute for persistence modules valued in the category of vector spaces. In the specific setting of multidimensional persistent homology we show that the problem is at least as hard as a matrix invertibility problem. Persistence modules valued in the category of sets are also studied. As a corollary, we obtain that the isomorphism problem for Reeb graphs is graph isomorphism complete.

Adam Brown and Bei Wang: *Sheaf-Theoretic Stratification Learning*
In this paper, we investigate a sheaf-theoretic interpretation of stratification learning. Motivated by the work of Alexandroff (1937) and McCord (1978), we aim to redirect efforts in the computational topology of triangulated compact polyhedra to the much more computable realm of sheaves on partially ordered sets. Our main result is the construction of stratification learning algorithms framed in terms of a sheaf on a partially ordered set with the Alexandroff topology. We prove that the resulting decomposition is the unique minimal stratification for which the strata are homogeneous and the given sheaf is constructible. In particular, when we choose to work with the local homology sheaf, our algorithm gives an alternative to the local homology transfer algorithm given in Bendich et al. (2012), and the cohomology stratification algorithm given in Nanda (2017). We envision that our sheaf-theoretic algorithm could give rise to a larger class of stratification beyond homology-based stratification. This approach also points toward future applications of sheaf theory in the study of topological data analysis by illustrating the utility of the language of sheaf theory in generalizing existing algorithms.

Mickaël Buchet and Emerson G. Escolar: *Realization of Indecomposable Persistence Modules of Arbitrarily Large Dimension*
While persistent homology has taken strides towards becoming a widespread tool for data analysis, multidimensional persistence has proven more difficult to apply. One reason is the serious drawback of no longer having a concise and complete descriptor analogous to the persistence diagrams of the former. We propose a simple algebraic construction to illustrate the existence of infinite families of indecomposable persistence modules over regular grids of sufficient size. On top of providing a constructive proof of representation infinite type, we also provide realizations by topological spaces and Vietoris-Rips filtrations, showing that they can actually appear in real data and are not the product of degeneracies.

Kevin Buchin, Jeff Phillips and Pingfan Tang: *Approximating the Distribution of the Median and other Robust Estimators on Uncertain Data*
Robust estimators, like the median of a point set, are important for data analysis

in the presence of outliers. We study robust estimators for locationally uncertain points with discrete distributions. That is, each point in a data set has a discrete probability distribution describing its location. The probabilistic nature of uncertain data makes it challenging to compute such estimators, since the true value of the estimator is now described by a distribution rather than a single point. We show how to construct and estimate the distribution of the median of a point set. Building the approximate support of the distribution takes near-linear time, and assigning probability to that support takes quadratic time. We also develop a general approximation technique for distributions of robust estimators with respect to ranges with bounded VC dimension. This includes the geometric median for high dimensions and the Siegel estimator for linear regression.

Boris Bukh, Xavier Goaoc, Alfredo Hubard and Matthew Trager: *Consistent Sets of Lines with No Colorful Incidence*

We consider incidences among colored sets of lines in $\mathbb{R}^3$ and examine whether the existence of certain concurrences between lines of k colors force the existence of at least one concurrence between lines of $k+1$ colors. This question is motivated by shape analysis and 3D reconstruction from multiple views in computer vision.

Benjamin A. Burton: *The HOMFLY-PT Polynomial is Fixed-Parameter Tractable*

Many polynomial invariants of knots and links, including the Jones and HOMFLY-PT polynomials, are widely used in practice but #P-hard to compute. It was shown by Makowsky in 2001 that computing the Jones polynomial is fixed-parameter tractable in the treewidth of the link diagram, but the parameterised complexity of the more powerful HOMFLY-PT polynomial remained an open problem. Here we show that computing HOMFLY-PT is fixed-parameter tractable in the treewidth, and we give the first sub-exponential time algorithm to compute it for arbitrary links.

Ludovic Calès, Apostolos Chalkis, Ioannis Emiris and Vissarion Fisikopoulos: *Practical Volume Computation of Structured Convex Bodies, and an Application to Modeling Portfolio Dependencies and Financial Crises*

We examine volume computation of general-dimensional polytopes and more general convex bodies, defined as the intersection of a simplex by a family of parallel hyperplanes, and another family of parallel hyperplanes or a family of concentric ellipsoids. Such convex bodies appear in modeling and predicting financial crises. The impact of crises on the economy (labor, income, etc.) makes its detection of prime interest for the public in general and for policy makers in particular. Certain features of dependencies in the markets clearly identify times of turmoil. We describe the relationship between asset characteristics by means of a copula; each characteristic is either a linear or quadratic form of the portfolio components, hence the copula can be constructed by computing volumes of convex bodies. We design and implement practical algorithms in the exact and approximate setting, we experimentally juxtapose them and study the tradeoff of exactness and accuracy for speed. We analyze the following methods in order of increasing generality: rejection sampling relying on uniformly sampling the simplex, which is the fastest approach, but inaccurate for small volumes; exact formulae based on the computation of integrals of probability distribution functions, which are the method of choice for intersections with a single hyperplane; an optimized Lawrence sign decomposition method, since the polytopes at hand are shown to be simple with additional structure; Markov chain Monte Carlo algorithms using random walks based on the hit-and-run paradigm generalized to nonlinear convex bodies and relying on new methods for computing a ball enclosed in the given body, such as a second-order cone program; the latter is experimentally extended to non-convex bodies with very encouraging results. Our C++ software, based on CGAL and Eigen and available on github, is shown to be very effective in up to 100 dimensions. Our results offer novel, effective means of computing portfolio dependencies and an indicator of financial crises, which is shown to correctly identify past crises.

Jean Cardinal, Timothy M. Chan, John Iacono, Stefan Langerman and Aurélien Ooms: *Subquadratic Encodings for Point Configurations*

For most algorithms dealing with sets of points in the plane, the only relevant information carried by the input is the combinatorial configuration of the points: the orientation of each triple of points in the set (clockwise, counterclockwise, or collinear). This information is called the order type of the point set. In the dual, realizable order types and abstract order types are combinatorial analogues of line arrangements and pseudoline arrangements. Too often in the literature we analyze algorithms in the real-RAM model for simplicity, putting aside the fact that computers as we know them cannot handle arbitrary real numbers without some sort of encoding. Encoding an order type by the integer coordinates of some realizing point set is known to yield doubly exponential coordinates in some cases. Other known encodings can achieve quadratic space or fast orientation queries, but not both. In this contribution, we give a compact encoding for abstract order types that allows efficient query of the orientation of any triple: the encoding uses $O(n^2)$ bits and an orientation query takes $O(\log n)$ time in the word-RAM model. This encoding is space-optimal for abstract order types. We show how to shorten the encoding to $O(n^2(\log\log n)^2/\log n)$ bits for realizable order types, giving the first subquadratic encoding for those order types with fast orientation queries. We further refine our encoding to attain $O(\log n/\log\log n)$ query time without blowing up the space requirement. In the realizable case, we show that all those encodings can be computed efficiently. Finally, we generalize our results to the encoding of point configurations in higher dimension.

Timothy Carpenter, Anastasios Sidiropoulos, Daniel Lokshtanov, Fedor Fomin and Saket Saurabh: *Algorithms for Low-Distortion Embeddings into Arbitrary 1-Dimensional Spaces*

We study the problem of finding a minimum-distortion embedding of the shortest path metric of an unweighted graph into a "simpler" metric X. Computing such an embedding (exactly or approximately) is a non-trivial task even when X is the metric induced by a path, or, equivalently, into the real line. In this paper we give approximation and fixed-parameter tractable (FPT) algorithms for minimum-distortion embeddings into the metric of a subdivision of some fixed graph H, or, equivalently, into any fixed 1-dimensional simplicial complex. More precisely, we study the following problem: For given graphs G, H and integer c, is it possible to embed G with distortion c into a graph homeomorphic to H? Then embedding into the line is the special case $H = K_2$, and embedding into the cycle is the case $H = K_3$, where K_k denotes the complete graph on k vertices. For this problem we give

- An approximation algorithm, which in time $f(H)poly(n)$, for some function f, either correctly decides that there is no embedding of G with distortion c into any graph homeomorphic to H, or finds an embedding with distortion $poly(c)$;

- An exact algorithm, which in time $f'(H,c)poly(n)$, for some function f', either correctly decides that there is no embedding of G with distortion c into any graph homeomorphic to H, or finds an embedding with distortion c.

Prior to our work, $poly(OPT)$-approximation or FPT algorithms were known only for embedding into paths and trees of bounded degrees.

Jérémie Chalopin, Victor Chepoi, Feodor F. Dragan, Guillaume Ducoffe, Abdulhakeem Mohammed and Yann Vaxès: *Fast Approximation and Exact Computation of Negative Curvature Parameters of Graphs*

Gromov hyperbolicity and related graph-parameters represent how close (locally) the shortest-path metric of a graph is to a tree metric. The Gromov hyperbolicity of a given graph can be computed in polynomial-time, however it is unlikely that it can be done faster than in supercubic time. This makes this parameter difficult to compute, or even to approximate, on large graphs. In this paper, we provide a simple factor 8 approximation algorithm for computing Gromov hyperbolicity of an n-vertex unweighted graph $G = (V, E)$ in optimal time $O(n^2)$ (given the distance matrix of G as the input). This algorithm leads to constant factor approximations of other graph-parameters related to hyperbolicity: thinness, slimness, and insize. We also present efficient algorithms for exact computation of these parameters. To our best knowledge, the latter parameters were not known to be polynomial-time computable until this note.

Timothy M. Chan: *Tree Drawings Revisited*

We make progress on a number of open problems concerning the area requirement for drawing trees on a grid. We prove that

1. every tree of size n (with arbitrarily large degree) has a straight-line drawing with area $n2^{O(\sqrt{\log\log n \log\log\log n})}$, improving the longstanding $O(n \log n)$ bound;

2. every tree of size n (with arbitrarily large degree) has a straight-line upward drawing with area $n\sqrt{\log n}(\log\log n)^{O(1)}$, improving the longstanding $O(n \log n)$ bound;

3. every binary tree of size n has a straight-line orthogonal drawing with area $n2^{O(\log^* n)}$, improving the previous $O(n \log\log n)$ bound by Shin, Kim, and Chwa (1996) and Chan, Goodrich, Kosaraju, and Tamassia (1996);

4. every binary tree of size n has a straight-line order-preserving drawing with area $n2^{O(\log^* n)}$, improving the previous $O(n \log\log n)$ bound by Garg and Rusu (2003);

5. every binary tree of size n has a straight-line orthogonal order-preserving drawing with area $n2^{O(\sqrt{\log n})}$, improving the $O(n^{3/2})$ previous bound by Frati (2007).

Timothy M. Chan and Dimitrios Skrepetos: *Approximate Shortest Paths and Distance Oracles in Weighted Unit-Disk Graphs*

We give the first near-linear-time $(1+\varepsilon)$-approximation algorithm for the *diameter* of a weighted unit-disk graph of n vertices, running in $O\left(n \log^2 n\right)$ time for any constant $\varepsilon > 0$, considerably improving the near-$O\left(n^{3/2}\right)$-time algorithm of Gao and Zhang [STOC 2003]. We can also construct a $(1+\varepsilon)$-approximate *distance oracle* for weighted unit-disk graphs with $O(1)$ query time, with a similar improvement in the preprocessing time, from near $O\left(n^{3/2}\right)$ to $O\left(n \log^3 n\right)$. We obtain similar new results for a number of other related problems in the weighted unit-disk graph metric, such as the radius and bichromatic closest pair. As a further application, we use our new distance oracle, along with additional ideas, to solve the $(1+\varepsilon)$-approximate *all-pairs bounded-leg shortest paths* problem for a set of n planar points, with near $O\left(n^{2.579}\right)$ preprocessing time, $O\left(n^2 \log n\right)$ space, and $O\left(\log \log n\right)$ query time, improving the near-cubic preprocessing bound by Roditty and Segal [SODA 2007].

Timothy M. Chan and Konstantinos Tsakalidis: *Dynamic Planar Orthogonal Point Location in Sublogarithmic Time*

We study a longstanding problem in computational geometry: dynamic 2-d orthogonal point location, i.e., vertical ray shooting among n horizontal line segments. We present a data structure achieving $O\left(\frac{\log n}{\log \log n}\right)$ optimal expected query time and $O\left(\log^{1/2+\varepsilon} n\right)$ update time (amortized) in the word-RAM model for any constant $\varepsilon > 0$, under the assumption that the x-coordinates are integers bounded polynomially in n. This substantially improves previous results of Giyora and Kaplan [SODA 2007] and Blelloch [SODA 2008] with $O\left(\log n\right)$ query and update time, and of Nekrich (2010) with $O\left(\frac{\log n}{\log \log n}\right)$ query time and $O\left(\log^{1+\varepsilon} n\right)$ update time. Our result matches the best known upper bound for simpler problems such as dynamic 2-d dominance range searching. We also obtain similar bounds for orthogonal line segment intersection reporting queries, vertical ray stabbing, and vertical stabbing-max, improving previous bounds, respectively, of Blelloch [SODA 2008] and Mortensen [SODA 2003], of Tao (2014), and of Agarwal, Arge, and Yi [SODA 2005] and Nekrich [ISAAC 2011].

Frédéric Chazal and Vincent Divol: *The Density of Expected Persistence Diagrams and its Kernel Based Estimation*

Persistence diagrams play a fundamental role in Topological Data Analysis where they are used as topological descriptors of filtrations built on top of data. They consist in discrete multisets of points in the plane $\mathbb{R}^2$ that can equivalently be seen as discrete measures in $\mathbb{R}^2$. When the data come as a random point cloud, these discrete measures become random measures whose expectation is studied in this paper. First, we show that for a wide class of filtrations, including the Čech and Rips-Vietoris filtrations, the expected persistence diagram, that is a deterministic measure on $\mathbb{R}^2$, has a density with respect to the Lebesgue measure. Second, building on the previous result we show that the persistence surface recently introduced in [H. Adams et al., Journal of Machine Learning Research 18.8 (2017)] can be seen as a kernel estimator of this density. We propose a cross-validation scheme for selecting an optimal bandwidth, which is proven to be a consistent procedure to estimate the density.

Éric Colin de Verdière, Thomas Magnard and Bojan Mohar: *Embedding Graphs into Two-Dimensional Simplicial Complexes*

We consider the problem of deciding whether an input graph G admits a topological embedding into a two-dimensional simplicial complex C. This problem includes, among others, the embeddability problem of a graph on a surface and the topological crossing number of a graph, but is more general.The problem is NP-complete when C is part of the input, and we give a polynomial-time algorithm if the complex C is fixed. Our strategy is to reduce the problem into an embedding extension problem on a surface, which has the following form: Given a subgraph H' of a graph G', and an embedding of H' on a surface S, can that embedding be extended to an embedding of G'? Such problems can be solved, in turn, using a key component in Mohar's algorithm to decide the embeddability of a graph on a fixed surface (STOC 1996, SIAM J. Discr. Math. 1999).

Roee David, Karthik C. S. and Bundit Laekhanukit: *On the Complexity of Closest Pair via Polar-Pair of Point-Sets*

Every graph G can be represented by a collection of equi-radii spheres in a d-dimensional metric Δ such that there is an edge uv in G if and only if the spheres corresponding to u and v intersect. The smallest integer d such that G can be represented by a collection of spheres (all of the same radius) in Δ is called the sphericity of G, and if the collection of spheres are non-overlapping, then the value d is called the contact-dimension of G. In this paper, we study the sphericity and contact dimension of the complete bipartite graph $K_{n,n}$ in various L^p-metrics and consequently connect the complexity of the monochromatic closest pair and bichromatic closest pair problems.

Erik D. Demaine, Sándor Fekete, Phillip Keldenich, Henk Meijer and Christian Scheffer: *Coordinated Motion Planning: Reconfiguring a Swarm of Labeled Robots with Bounded Stretch*

We present a number of breakthroughs for coordinated motion planning, in which the objective is to reconfigure a swarm of labeled convex objects by a combination of parallel, continuous, collision-free translations into a given target arrangement. Problems of this type can be traced back to the classic work of Schwartz and Sharir (1983), who gave a method for deciding the existence of a coordinated motion for a set of disks between obstacles; their approach is polynomial in the complexity of the obstacles, but exponential in the number of disks. Despite a broad range of other non-trivial results for multi-object motion planning, previous work has largely focused on sequential schedules, in which one robot moves at a time, with objectives such as the number of moves; attempts to minimize the overall makespan of a coordinated parallel motion schedule (with many robots moving simultaneously) have defied all attempts at establishing the complexity in the absence of obstacles, as well as the existence of efficient approximation methods. We resolve these open problems by developing a framework that provides constant-factor approximation algorithms for minimizing the execution time of a coordinated, parallel motion plan for a swarm of robots in the absence of obstacles, provided their arrangement entails some amount of separability. In fact, our algorithm achieves constant stretch factor: If all robots want to move at most d units from their respective starting positions, then the total duration of the overall schedule (and hence the distance tracveled by each robot) is $O(d)$. Various extensions include unlabeled robots and different classes of robots. We also resolve the complexity of finding a reconfiguration plan with minimal execution time by proving that this is NP-hard, even for a grid arrangement without any stationary obstacles. On the other hand, we show that for densely packed disks that cannot be well separated, a stretch factor $\Omega(N^{1/4})$ may be required. On the positive side, we establish a stretch factor of $O(N^{1/2})$ even in this case. The intricate difficulties of computing precise optimal solutions are demonstrated by the seemingly simple case of just two disks, which is shown to be excruciatingly difficult to solve to optimality.

Olivier Devillers, Sylvain Lazard and William Lenhart: *3D Snap Rounding*
Let $\mathcal{P}$ be a set of n polygons in $\mathbb{R}^3$, each of constant complexity and with pairwise disjoint interiors. We propose a rounding algorithm that maps $\mathcal{P}$ to a simplicial complex $\mathcal{Q}$ whose vertices have integer coordinates. Every face of $\mathcal{P}$ is mapped to a set of faces (or edges or vertices) of $\mathcal{Q}$ and the mapping from $\mathcal{P}$ to $\mathcal{Q}$ can be done through a continuous motion of the faces such that (i) the L_∞ Hausdorff distance between a face and its image during the motion is at most 3/2 and (ii) if two points become equal during the motion, they remain equal through the rest of the motion. In the worse the size of $\mathcal{Q}$ is $O(n^{15})$ and the time complexity of the algorithm is $O(n^{19})$ but, under reasonable hypotheses, these complexities decrease to $O(n^5)$ and $O(n^6\sqrt{n})$.

Tamal Dey, Jiayuan Wang and Yusu Wang: *Graph Reconstruction by Discrete Morse Theory*
Recovering hidden graph-like structures from potentially noisy data is a fundamental task in modern data analysis. Recently, a persistence-guided discrete Morse-based framework to extract a geometric graph from low-dimensional data has become popular. However, to date, there is very limited theoretical understanding of this framework in terms of graph reconstruction. This paper makes a first step towards closing this gap. Specifically, first, leveraging existing theoretical understanding of persistence-guided discrete Morse cancellation, we provide a simplified version of the existing discrete Morse-based graph reconstruction algorithm. We then introduce a simple and natural noise model and show that the aforementioned framework can correctly reconstruct a graph under this noise model, in the sense that it has the same topology as the hidden ground-truth graph, and is also geometrically close. We also provide some experimental results for our simplified graph-reconstruction

algorithm.

Tamal Dey and Cheng Xin: *Computing Bottleneck Distance for 2-D Interval Decomposable Modules*

Computation of the interleaving distance between persistence modules is a central task in topological data analysis. For 1-D persistence modules, thanks to the isometry theorem, this can be done by computing the bottleneck distance with known efficient algorithms. The question is open for most n-D persistence modules, $n > 1$, because of the well recognized complications of the indecomposables. In this paper, we consider a reasonably complicated class called *2-D interval decomposable* modules whose indecomposables may have a description of non-constant complexity. We present a polynomial time algorithm to compute the bottleneck distance for these modules from indecomposables which bounds the interleaving distance from above, and provide another algorithm to compute a new distance called *dimension distance* that bounds it from below.

Zdenek Dvorak, Petr Hlineny and Bojan Mohar: *Structure and Generation of Crossing-Critical Graphs*

We study c-crossing-critical graphs, which are the minimal graphs that require at least c pairwise edge crossings when drawn in the plane. For $c = 1$ there are only two such graphs without degree-2 vertices, K_5 and $K_3, 3$, but for any $c > 1$ there exist infinitely many c-crossing-critical graphs. It has been previously shown that c-crossing-critical graphs have bounded path-width and contain only a bounded number of internally disjoint paths between any two vertices. We expand on these results, providing a more detailed description of the structure of crossing-critical graphs. On the way towards this description, we prove a new structural characterisation of plane graphs of bounded path-width. Then we show that every c-crossing-critical graph can be obtained from a c-crossing-critical graph of bounded size by replicating bounded-size parts that already appear in narrow "bands" or "fans" in the graph. This also gives an algorithm to generate all the c-crossing-critical graphs of at most given order in polynomial time per each generated graph.

Herbert Edelsbrunner and Georg Osang: *The Multi-Cover Persistence of Euclidean Balls*

Given a locally finite $X \subseteq \mathbb{R}^d$ and a radius $r \geq 0$, the k-fold cover of X and r consists of all points in $\mathbb{R}^d$ that have k or more points of X within distance r. We consider two filtrations — one in scale obtained by fixing k and increasing r, and the other in depth obtained by fixing r and decreasing k — and we compute the persistence diagrams of both. While standard methods suffice for the filtration in scale, we need novel geometric and topological concepts for the filtration in depth. In particular, we introduce a rhomboid tiling in $\mathbb{R}^{d+1}$ whose horizontal integer slices are the order-k Delaunay mosaics of X, and construct a zigzag module from Delaunay mosaics that is isomorphic to the persistence module of the multi-covers.

Herbert Edelsbrunner, Žiga Virk and Hubert Wagner: *Smallest Enclosing Spheres and Chernoff Points in Bregman Geometry*

Smallest enclosing spheres of finite point sets are central to methods in topological data analysis. Focusing on Bregman divergences to measure dissimilarity, we prove bounds on the location of the center of a smallest enclosing sphere that depend on the range of radii for which Bregman balls are convex.

Michael Elkin and Ofer Neiman: *Near Isometric Terminal Embeddings for Doubling Metrics*

Given a metric space (X, d), a set of terminals $K \subseteq X$, and a parameter $t \geq 1$, we consider metric structures (e.g., spanners, distance oracles, embedding into normed spaces) that preserve distances for all pairs in $K \times X$ up to a factor of t, and have small size (e.g. number of edges for spanners, dimension for embeddings). While such terminal (aka source-wise) metric structures are known to exist in several settings, no terminal spanner or embedding with distortion close to 1, i.e., $t = 1 + \epsilon$ for some small $0 < \epsilon < 1$, is currently known. Here we devise such terminal metric structures for *doubling* metrics, and show that essentially any metric structure with distortion $1+\epsilon$ and size $s(|X|)$ has its terminal counterpart, with distortion $1+O(\epsilon)$ and size $s(|K|) + 1$. In particular, for any doubling metric on n points, a set of $k = o(n)$ terminals, and constant $0 < \epsilon < 1$, there exists

- A spanner with stretch $1 + \epsilon$ for pairs in $K \times X$, with $n + o(n)$ edges.
- A labeling scheme with stretch $1+\epsilon$ for pairs in $K \times X$, with label size $\approx \log k$.
- An embedding into ℓ_∞^d with distortion $1 + \epsilon$ for pairs in $K \times X$, where $d = O(\log k)$.

Moreover, surprisingly, the last two results apply if only K is a doubling metric, while X can be arbitrary.

Ioannis Emiris and Ioannis Psarros: *Products of Euclidean Metrics and Applications to Proximity Questions among Curves*

The problem of Approximate Nearest Neighbor (ANN) search is fundamental in computer science and has benefited from significant progress in the past couple of decades. However, most work has been devoted to pointsets whereas complex shapes have not been sufficiently treated. Here, we focus on distance functions between discretized curves in Euclidean space: they appear in a wide range of applications, from road segments to time-series in general dimension. For ℓ_p-products of Euclidean metrics, for any p, we design simple and efficient data structures for ANN, based on randomized projections, which are of independent interest. They serve to solve proximity problems under a notion of distance between discretized curves, which generalizes both discrete Fréchet and Dynamic Time Warping distances. These are the most popular and practical approaches to comparing such curves. We offer the first data structures and query algorithms for ANN with arbitrarily good approximation factor, at the expense of increasing space usage and preprocessing time over existing methods. Query time complexity is comparable or significantly improved by our algorithms; our algorithm is especially efficient when the length of the curves is bounded.

Stefan Felsner, Linda Kleist, Torsten Mütze and Leon Sering: *Rainbow Cycles in Flip Graphs*

The flip graph of triangulations has as vertices all triangulations of a convex n-gon, and an edge between any two triangulations that differ in exactly one edge. An r-rainbow cycle in this graph is a cycle in which every inner edge of the triangulation appears exactly r times.This notion of a rainbow cycle extends in a natural way to other flip graphs. In this paper we investigate the existence of r-rainbow cycles for three different flip graphs on geometric classes of objects: the aforementioned flip graph of triangulations of a convex n-gon, the flip graph of plane spanning trees on an arbitrary set of n points, and the flip graph of non-crossing perfect matchings on a set of n points in convex position. In addition, we consider two flip graphs on classes of non-geometric objects: the flip graph of permutations of $\{1, 2, \ldots, n\}$ and the flip graph of k-element subsets of $\{1, 2, \ldots, n\}$. In each of the five settings, we prove the existence and non-existence of rainbow cycles for different values of r, n and k.

Radoslav Fulek and Jan Kynčl: *Hanani–Tutte for Approximating Maps of Graphs*

We resolve in the affirmative conjectures of A. Skopenkov and Repovš (1998), and M. Skopenkov (2003) generalizing the classical Hanani–Tutte theorem to the setting of approximating maps of graphs on 2-dimensional surfaces by embeddings. Our proof of this result is constructive and almost immediately implies an efficient algorithm for testing if a given piecewise linear maps of a graph in a surface is approximable by an embedding. More precisely, an instance of this problem consists of (i) a graph G whose vertices are partitioned into clusters and whose inter-cluster edges are partitioned into bundles, and (ii) a region R of on a 2-dimensional compact surface M without boundary given as the union of a set of pairwise disjoint discs corresponding to the clusters and a set of pairwise non-intersecting “pipes” corresponding to the bundles, connecting certain pairs of these discs. We are to decide whether G can be embedded inside M so that the vertices in every cluster are drawn in the corresponding disc, the edges in every bundle pass only through its corresponding pipe, and every edge crosses the boundary of each disc at most once.

Radoslav Fulek and Jan Kynčl: *The $\mathbb{Z}_2$-Genus of Kuratowski Minors*

A drawing of a graph on a surface is independently even if every pair of independent edges in the drawing crosses an even number of times. The $\mathbb{Z}_2$-genus of a graph G is the minimum g such that G has an independently even drawing on the orientable surface of genus g. An unpublished result by Robertson and Seymour implies that for every t, every graph of sufficiently large genus contains as a minor a projective $t \times t$ grid or one of the following so-called t-Kuratowski graphs: $K_{3,t}$, or t copies of K_5 or $K_{3,3}$ sharing at most 2 common vertices. We show that the $\mathbb{Z}_2$-genus of graphs in these families is unbounded in t; in fact, equal to their genus. Together, this implies that the genus of a graph is bounded from above by a function of its $\mathbb{Z}_2$-genus, solving a problem posed by Schaefer and Štefankovič, and giving an approximate version of the Hanani-Tutte theorem on surfaces.

Xavier Goaoc, Pavel Paták, Zuzana Patáková, Martin Tancer and Uli

Wagner: *Shellability is NP-Complete*

We prove that for every $d \geq 2$, deciding if a pure, d-dimensional, simplicial complex is shellable is NP-hard, hence NP-complete. This resolves a question raised, e.g., by Danaraj and Klee in 1978. Our reduction also yields that for every $d \geq 2$ and $k \geq 0$, deciding if a pure, d-dimensional, simplicial complex is k-decomposable is NP-hard. For $d \geq 3$, both problems remain NP-hard when restricted to contractible pure d-dimensional complexes.

Arthur van Goethem and Kevin Verbeek: *Optimal Morphs of Planar Orthogonal Drawings*

We describe an algorithm that morphs between two planar orthogonal drawings Γ_i and Γ_o of a graph G, while preserving planarity and orthogonality. Necessarily Γ_i and Γ_o share the same combinatorial embedding. Our morph uses a linear number of horizontal and vertical linear morphs (linear interpolations between two drawings) and preserves linear complexity throughout the process, thereby answering an open question from Biedl et al. Our algorithm first unifies the two drawings to ensure an equal number of (virtual) bends on each edge. We then interpret bends as vertices which form obstacles for so-called wires: horizontal and vertical lines separating the vertices of Γ_o. These wires define homotopy classes with respect to the vertices of G (for the combinatorial embedding of G shared by Γ_i and Γ_o). These homotopy classes can be represented by orthogonal polylines in Γ_i. We argue that the structural difference between the two drawings can be captured by the *spirality* of the wires in Γ_i, which guides our morph from Γ_i to Γ_o.

Joshua Grochow and Jamie Tucker-Foltz: *Computational Topology and the Unique Games Conjecture*

Covering spaces of graphs have long been useful for studying expanders (as 'graph lifts') and unique games (as the 'label-extended graph'). In this paper we advocate for the thesis that there is a much deeper relationship between algebraic topology and the Unique Games Conjecture. Our starting point is the observation that the only known problems whose inapproximability is equivalent to the Unique Games Conjecture - Unique Games and Max-2Lin - are instances of Maximum Section of a Covering Space on graphs. We then observe that the reduction between these two problems (Khot-Kindler-Mossel-O'Donnell, FOCS '04; SICOMP '07) gives a well-defined map of covering spaces. We further prove that inapproximability for Maximum Section of a Covering Space on (cell decompositions of) closed 2-manifolds is also equivalent to the Unique Games Conjecture. This gives the first new 'Unique Games-complete' problem in over a decade. Our results essentially settle an open question of Chen and Freedman (SODA, 2010; Disc. Comput. Geom., 2011) from computational geometry, by showing that their question is almost equivalent to the Unique Games Conjecture. (The main difference is that they ask for inapproximability over the integers mod2, and we show Unique Games-completeness over the integers mod$q$ for large q.) This equivalence comes from the fact that when the structure group G of the covering space is Abelian - or more generally for principal G-bundles - Maximum Section of a G-Covering Space is the same as the well-studied problem of 1-Homology Localization.Although our most technically demanding result is an application of Unique Games to computational geometry, we hope that our observations on the topological nature of the Unique Games Conjecture will lead to applications of algebraic topology to the Unique Games Conjecture in the future.

Andreas Haas: *Solving Large-Scale Minimum-Weight Triangulation Instances to Provable Optimality*

We consider practical methods for the problem of finding a minimum-weight triangulation (MWT) of a planar point set, a classic problem of computational geometry with many applications. While Mulzer and Rote proved in 2006 that computing an MWT is NP-hard, Beirouti and Snoeyink showed in 1998 that computing provably optimal solutions for MWT instances of up to 80,000 *uniformly distributed* points is possible, making use of clever heuristics that are based on geometric insights. We show that these techniques can be refined and extended to instances of much bigger size and different type, based on an array of modifications and parallelizations in combination with more efficient geometric encodings and data structures. As a result, we are able to solve MWT instances with up to 30,000,000 uniformly distributed points in less than 4 minutes to provable optimality. Moreover, we can compute optimal solutions for a vast array of other benchmark instances that are *not* uniformly distributed, including normally distributed instances (up to 30,000,00 points), all point sets in the TSPLIB (up to 85,900 points), and VLSI instances with up to 744,710 points. This demonstrates that from a practical point of view, MWT instances can be handled quite well, despite their theoretical difficulty.

Ivor Hoog V.D., Elena Khramtcova and Maarten Löffler: *Dynamic Smooth Compressed Quadtrees*

We introduce dynamic smooth (aka balanced) compressed quadtrees with worst-case constant time updates in constant dimensions. We distinguish two versions of the problem. First, we show that quadtrees as a space-division data structure can be made smooth and dynamic subject to split and merge operations on the quadtree cells. Second, we show that quadtrees used to store a set of points in $\mathbb{R}^d$ can be made smooth and dynamic subject to insertions and deletions of points. The second version uses the first but must additionally deal with compression and alignment of quadtree components. In both cases our updates take $2^{O(d\log(d))}$, except for the point location part in the second version which is known to have a lower bound of $\Theta(\log n)$ — but if a pointer (finger) to the correct quadtree cell is given, the rest of the updates take worst-case constant time. Our result implies that several classic and recent results (ranging from ray tracing to planar point location) in computational geometry which use quadtrees can be implemented on a real RAM pointer machine.

Kristóf Huszár, Jonathan Spreer and Uli Wagner: *On the Treewidth of Triangulated 3-Manifolds*

In graph theory, as well as in 3-manifold topology, there exist several width-type parameters to describe how 'simple' or 'thin' a given graph or 3-manifold is. These parameters, such as pathwidth or treewidth for graphs, or the concept of thin position for 3-manifolds, play an important role when studying algorithmic problems; in particular, there is a variety of problems in computational 3-manifold topology - some of them known to be computationally hard in general - that become solvable in polynomial time as soon as the dual graph of the input triangulation has bounded treewidth. In view of these algorithmic results, it is natural to ask whether every 3-manifold admits a triangulation of bounded treewidth. We show that this is not the case, i.e., that there exists an infinite family of closed 3-manifolds not admitting triangulations of bounded pathwidth or treewidth (the latter implies the former, but we present two separate proofs). We derive these results from work of Agol and of Scharlemann and Thompson, by exhibiting explicit connections between the topology of a 3-manifold M on the one hand and width-type parameters of the dual graphs of triangulations of M on the other hand, answering a question that had been raised repeatedly by researchers in computational 3-manifold topology. In particular, we show that if a closed, orientable, irreducible, non-Haken 3-manifold M has a triangulation of treewidth (resp. pathwidth) k then the Heegaard genus of M is at most $48(k+1)$ (resp. $4(3k+1)$).

Tanmay Inamdar and Kasturi Varadarajan: *On Partial Covering For Geometric Set Systems*

We study a generalization of the Set Cover problem called the Partial Set Cover in the context of geometric set systems. The input to this problem is a set system (X, S), where X is a set of elements and S is a collection of subsets of X, and an integer $k \leq |X|$. The goal is to cover at least k elements of X by using a minimum-weight collection of sets from S. In the geometric version, X typically consists of points in $\mathbb{R}^d$, and S contains sets induced by geometric objects of a certain kind. The main result of this article is an LP rounding scheme which shows that the integrality gap of the Partial Set Cover LP is at most a constant times that of the Set Cover LP for the same class of geometric objects. As a corollary of this result, we get improved approximation guarantees for the Partial Set Cover problem for a large class of geometric set systems.

Bruno Jartoux and Nabil H. Mustafa: *Optimality of Geometric Local Search*

Up until nine years ago, the algorithmic status of several basic NP-complete problems in geometric combinatorial optimisation was unsolved. This included the existence of PTASs for hitting set, set cover, dominating set, independent set, and so on for some basic geometric objects. These past nine years have seen the resolution of all these—interestingly, with the same algorithm: geometric local search. In fact, it was shown that for all these problems, a k-local-search algorithm gives a $(1 + 1/\sqrt{k})$-approximation. This implies the existence of a PTAS for all these prolems with a running time of $O(n^(1/\varepsilon^2))$. Well-known hardness results show that it is not possible to have an algorithm with running time polynomial in n and $1/\varepsilon$. Thus the main open question left open is improving the exponent of n to $o(1/\varepsilon^2)$. In particular, it has been conjectured that a k-local search algorithm gives a $(1+o(1/\sqrt{k}))$-approximation.In this paper, we show that in fact the approximation guarantee of standard local search cannot be improved for any of these problems. The key ingredient is a new lower-bound for Hall's theorem for k-expanding planar graphs, which is then used to show the impossibility results.

Yifei Jin, Jian Li and Wei Zhan: *Odd Yao-Yao Graphs may not be Spanners*

It is a long-standing open problem whether Yao-Yao graphs YY_k are all spanners. Bauer and Damian showed that all YY_{6k} for $k \geq 6$ are spanners. Li and Zhan generalized their result and proved that all even Yao-Yao graphs YY_{2k} are spanners (for $k \geq 42$). However, their technique cannot be extended to odd Yao-Yao graphs, and whether they are spanners are still elusive. In this paper, we show that, surprisingly, for any integer $k \geq 1$, there exist odd Yao-Yao graph YY_{2k+1} instances, which are not spanners.

Kolja Junginger and Evanthia Papadopoulou: *Deletion in Abstract Voronoi Diagrams in Expected Linear Time*

Updating an abstract Voronoi diagram in linear time, after deletion of one site, has been a long standing open problem. Similarly for various concrete Voronoi diagrams of generalized sites, other than points. In this paper we present a simple, expected linear-time algorithm to update an abstract Voronoi diagram after deletion. To this aim, we introduce the concept of a *Voronoi-like diagram*, a relaxed version of a Voronoi construct, that has a structure similar to an abstract Voronoi diagram, without however being one. We use Voronoi-like subdivisions as intermediate structures, which are much simpler to compute, thus, making an expected linear-time construction possible. We formalize the concept and prove that it is robust under an *insertion* operation, thus, enabling its use in (randomized) incremental constructions.

Chaya Keller and Shakhar Smorodinsky: *From a $(p, 2)$-Theorem to a Tight (p, q)-Theorem*

A family $\mathcal{F}$ of sets is said to satisfy the (p, q)-property if among any p sets of $\mathcal{F}$ some q have a non-empty intersection. The celebrated (p, q)-theorem of Alon and Kleitman asserts that any family of compact convex sets in $\mathbb{R}^d$ that satisfies the (p, q)-property for some $q \geq d+1$, can be pierced by a fixed number (independent on the size of the family) $f_d(p, q)$ of points. The minimum such piercing number is denoted by $HD_d(p, q)$. Already in 1957, Hadwiger and Debrunner showed that whenever $q > \frac{d-1}{d}p + 1$, the piercing number is $HD_d(p, q) = p - q + 1$; no exact values of $HD_d(p, q)$ were found ever since. While for an arbitrary family of compact convex sets in $\mathbb{R}^d$, $d \geq 2$, a $(p, 2)$-property does not imply a bounded piercing number, such bounds were proved for numerous specific families. The best-studied among them is axis-parallel boxes in $\mathbb{R}^d$, and specifically, axis-parallel rectangles in the plane. Wegner and (independently) Dol'nikov used a $(p, 2)$-theorem for axis-parallel rectangles to show that $HD_{\text{rect}}(p, q) = p - q + 1$ holds for all $q > \sqrt{2p}$. These are the only values of q for which $HD_{\text{rect}}(p, q)$ is known exactly. In this paper we present a general method which allows using a $(p, 2)$-theorem as a bootstrapping to obtain a tight (p, q)-theorem, for families with Helly number 2, even without assuming that the sets in the family are convex or compact. To demonstrate the strength of this method, we obtain a significant improvement of an over 50 year old result by Wegner and Dol'nikov. Namely, we show that $HD_{d-\text{box}}(p, q) = p - q + 1$ holds for all $q > c' \log^{d-1} p$, and in particular, $HD_{\text{rect}}(p, q) = p - q + 1$ holds for all $q \geq 7\log_2 p$ (compared to $q \geq \sqrt{2p}$ of Wegner and Dol'nikov). In addition, for several classes of families, we present improved $(p, 2)$-theorems, some of which can be used as a bootstrapping to obtain tight (p, q)-theorems. In particular, we show that any family $\mathcal{F}$ of compact convex sets in $\mathbb{R}^d$ with Helly number 2 admits a $(p, 2)$-theorem with piercing number $O(p^{2d-1})$, and thus, satisfies $HD_{\mathcal{F}}(p, q) = p - q + 1$ for all $q > cp^{1-\frac{1}{2d-1}}$, for a universal constant c.

Balázs Keszegh: *Coloring Intersection Hypergraphs of Pseudo-Disks*
We prove that the intersection hypergraph of a family of n pseudo-disks with respect to another family of pseudo-disks admits a proper coloring with 4 colors and a conflict-free coloring with $O(\log n)$ colors. Along the way we prove that the respective Delaunay-graph is planar. We also prove that the intersection hypergraph of a family of n regions with linear union complexity with respect to a family of pseudo-disks admits a proper coloring with constant many colors and a conflict-free coloring with $O(\log n)$ colors. Our results serve as a common generalization and strengthening of many earlier results, including ones about proper and conflict-free coloring points with respect to pseudo-disks, coloring regions of linear union complexity with respect to points and coloring disks with respect to disks.

Fabian Klute and Martin Nöllenburg: *Minimizing Crossings in Constrained Two-Sided Circular Graph Layouts*
Circular layouts are a popular graph drawing style, where vertices are placed on a circle and edges are drawn as straight chords. Crossing minimization in circular layouts is NP-hard. One way to allow for fewer crossings in practice are two-sided layouts that draw some edges as curves in the exterior of the circle. In fact, one- and two-sided circular layouts are equivalent to one-page and two-page book drawings. In this paper we study the problem of minimizing the crossings for a fixed cyclic vertex order by computing an optimal k-plane set of exteriorly drawn edges for k >= 1, extending the previously studied case k = 0. We show that this relates to finding bounded-degree maximum-weight induced subgraphs of circle graphs, which is a graph-theoretic problem of independent interest. We show NP-hardness for arbitrary k, present an efficient algorithm for k = 1, and generalize it to an explicit XP-time algorithm for any fixed k. For the practically interesting case k = 1 we implemented our algorithm and present experimental results that confirm the applicability of our algorithm.

Kevin Knudson and Bei Wang: *Discrete Stratified Morse Theory: A User's Guide*
Inspired by the works of Forman on discrete Morse theory, which is a combinatorial adaptation to cell complexes of classical Morse theory on manifolds, we introduce a discrete analog of the stratified Morse theory of Goresky and MacPherson (1988). We describe the basics of this theory and prove fundamental theorems relating the topology of a general simplicial complex with the critical simplices of a discrete stratified Morse function on the complex. We also provide an algorithm that constructs a discrete stratified Morse function out of an arbitrary function defined on a finite simplicial complex; this is different from simply constructing a discrete

Morse function on such a complex. We borrow Forman's idea of a 'user's guide', where we give simple examples to convey the utility of our theory.

Irina Kostitsyna, Bahram Kouhestani, Stefan Langerman and David Rappaport: *An Optimal Algorithm to Compute the Inverse Beacon Attraction Region*
The beacon model is a recent paradigm for guiding the trajectory of messages or small robotic agents in complex environments. A beacon is a fixed point with an attraction pull that can move points within a given polygon. Points move greedily towards a beacon: if unobstructed, they move along a straight line to the beacon, and otherwise they slide on the edges of the polygon. The Euclidean distance from a moving point to a beacon is monotonically decreasing. A given beacon attracts a point if the point eventually reaches the beacon. The problem of attracting all points within a polygon with a set of beacons can be viewed as a variation of the art gallery problem. Unlike most variations, the beacon attraction has the intriguing property of being asymmetric, leading to separate definitions of attraction region and inverse attraction region. The attraction region of a beacon is the set of points that it attracts. It is connected and can be computed in linear time for simple polygons. By contrast, it is known that the inverse attraction region of a point – the set of beacon positions that attract it – could have $\Omega(n)$ disjoint connected components. In this paper, we prove that, in spite of this, the total complexity of the inverse attraction region of a point in a simple polygon is linear, and present a $O(n \log n)$ time algorithm to construct it. This improves upon the best previous algorithm which required $O(n^3)$ time and $O(n^2)$ space. Furthermore we prove a matching $\Omega(n \log n)$ lower bound for this task in the algebraic computation tree model of computation, even if the polygon is monotone.

Marc Van Kreveld, Maarten Löffler and Lionov Wiratma: *On Optimal Polyline Simplification Using the Hausdorff and Fréchet Distance*
We revisit the classical polygonal line simplification problem and study it using the Hausdorff distance and Fréchet distance. Interestingly, no previous authors studied line simplification under these measures in its pure form, namely: for a given $\varepsilon > 0$, choose a minimum size subsequence of the vertices of the input such that the Hausdorff or Fréchet distance between the input and output polylines is at most ε. We analyze how the well-known Douglas-Peucker and Imai-Iri simplification algorithms perform compared to the optimum possible, also in the situation where the algorithms are given considerably larger values than ε. Furthermore, we show that computing an optimal simplification using the undirected Hausdorff distance is NP-hard. The same holds when using the directed Hausdorff distance from the input to the output polyline, whereas the reverse can be computed in polynomial time. Finally, we give a polynomial time algorithm to compute the optimal simplification under the Fréchet distance.

Thijs Laarhoven: *Graph-Based Time-Space Trade-Offs for Approximate Near Neighbors*
We take a first step towards a rigorous asymptotic analysis of graph-based approaches for finding (approximate) nearest neighbors in high-dimensional spaces, by analyzing the complexity of (randomized) greedy walks on the approximate near

neighbor graph. For random data sets of size $n = 2^{o(d)}$ on the d-dimensional Euclidean unit sphere, using near neighbor graphs we can provably solve the approximate nearest neighbor problem with approximation factor $c > 1$ in query time n^{r_q} and space n^{1+r_s}, for arbitrary $r_q, r_s > 0$ satisfying $(2c^2-1)r_q + 2c^2(c^2-1)\sqrt{r_s(1-r_s)} > c^4$. Graph-based near neighbor searching is especially competitive with hash-based methods for small c and near-linear memory, and in this regime the asymptotic scaling of a greedy graph-based search matches the recent optimal hash-based trade-offs of Andoni-Laarhoven-Razenshteyn-Waingarten [SODA'17]. We further study how the trade-offs scale when the data set is of size $n = 2^{O(d)}$, and analyze asymptotic complexities when applying these results to lattice sieving.

Chih-Hung Liu: *A Nearly Optimal Algorithm for the Geodesic Voronoi Diagram of Points in a Simple Polygon*

The geodesic Voronoi diagram of m point sites inside a simple polygon of n vertices is a subdivision of the polygon into m cells, one to each site, such that all points in a cell share the same nearest site under the geodesic distance. The best known lower bound for the construction time is $\Omega(n + m \log m)$, and a matching upper bound is a long-standing open question. The state-of-the-art construction algorithms achieve $O((n+m)\log(n+m))$ and $O(n+m\log m \log^2 n)$ time, which are optimal for $m = \Omega(n)$ and $m = O(n/\log^3 n)$, respectively. In this paper, we give a construction algorithm with $O(n+m(\log m+\log^2 n))$ time, and it is nearly optimal in the sense that if a single Voronoi vertex can be computed in $O(\log n)$ time, then the construction time will become the optimal $O(n + m\log m)$. In other words, we reduce the problem of constructing the diagram in the optimal time to the problem of computing a single Voronoi vertex in $O(\log n)$ time.

Leonardo Martínez-Sandoval, Edgardo Roldán-Pensado and Natan Rubin: *Further Consequences of the Colorful Helly Hypothesis*

Let $\mathcal{F}$ be a family of convex sets in $\mathbb{R}^d$, which are colored with $d+1$ colors. We say that $\mathcal{F}$ satisfies the Colorful Helly Property if every rainbow selection of $d+1$ sets, one set from each color class, has a non-empty common intersection. The Colorful Helly Theorem of Lovász states that for any such colorful family $\mathcal{F}$ there is a color class $F_i \subset \mathcal{F}$, for $1 \le i \le d+1$, whose sets have a non-empty intersection. We establish further consequences of the Colorful Helly hypothesis. In particular, we show that for each dimension $d \ge 2$ there exist numbers $f(d)$ and $g(d)$ with the following property: either one can find an additional color class whose sets can be pierced by $f(d)$ points, or all the sets in $\mathcal{F}$ can be crossed by $g(d)$ lines.

Malte Milatz: *Random Walks on Polytopes of Constant Corank*

We show that the pivoting process associated with one line and n points in r-dimensional space may need $\log^r(n)$ steps in expectation. Here $r = 0, 1, \ldots$ is considered a fixed parameter. The only case for which the bound was known previously was for $r \le 3$. Our lower bound is also valid for the expected number of pivoting steps in the following applications:

(i) The Random-Edge algorithm on linear programs with n constraints in $d = n-r$ variables;

(ii) the directed random walk on a grid polytope of corank r with n facets; and
(iii) the Random-Edge algorithm on an r-dimensional grid unique sink orientation of size n.

Victor Milenkovic, Elisha Sacks and Nabeel Butt: *Table Based Detection of Degenerate Predicates in Free Space Construction*
The key to a robust and efficient implementation of a computational geometry algorithm is an efficient algorithm for detecting degenerate (zero value) predicates. We study degeneracy detection in constructing the free space of apolyhedron that rotates around a fixed axis and translates freely relative to another polyhedron. The structure of the free space is determined by the signs of univariate polynomials in an angle parameter, called anglepolynomials, whose coefficients are multivariate polynomials in the coordinates of the vertices of the polyhedra. Every predicate is expressible as an angle polynomial f evaluated at a zero t of an angle polynomial g. A predicate is degenerate when t is a zero of a common factor of f and g. We present an efficient degeneracy detection algorithm based on a one-time factoring of every possible angle polynomial. Our algorithm is 3500 times faster than the standard algorithm based on greatest common divisorcomputation. In a complex geometric construction, the efficient algorithm reduces the cost of degeneracy detection from 90% of the total running time to 0.5%.

Eunjin Oh and Hee-Kap Ahn: *Approximate Range Queries for Clustering*
We study the approximate range searching for three variants of the clustering problem with a set P of n points in d-dimensional Euclidean space and axis-parallel rectangular range queries: the *k-median*, *k-means*, and*k-center range-clustering query problems*. We present data structures and query algorithms that compute $(1 + \varepsilon)$-approximations to the optimal clusterings of $P \cap Q$ efficiently for a query consisting of an orthogonal range Q, an integer k, and a value $\varepsilon > 0$.

Eunjin Oh and Hee-Kap Ahn: *Point Location in Dynamic Planar Subdivisions*
We study the point location problem on dynamic planar subdivisions that allows insertions and deletions of edges. We present a data structure of linear size for such a dynamic planar subdivision that supports sublinear-time update and polylogarithmic-time query. Precisely, the update time is $O(\sqrt{n/\log\log n})$ and the query time is $O(\log n(\log\log n)^2)$, where n is the number of edges in the subdivision. This answers a question posed by Snoeyink in the Handbook of Computational Geometry. When only deletions of edges are allowed, the update time and query time are just $O(\alpha(n))$ and $O(\log n)$, respectively.

Joseph O'Rourke: *Edge-Unfolding Nearly Flat Convex Caps*
The main result of this paper is a proof that a nearly flat, acutely triangulated convex cap C has an edge-unfolding to a non-overlapping polygon in the plane. A convex cap is the intersection of the surface of a convex polyhedron and a halfspace. 'Nearly flat' means that every face normal forms a sufficiently small angle $\phi < \Phi$ with the z-axis orthogonal to the halfspace bounding plane. The size of Φ depends on the acuteness gap: if every triangle angle is at most $\pi/2 - \alpha$, then $\Phi = 0.3\sqrt{\alpha}$

suffices; e.g., for $\alpha = 3deg$, $\Phi\ = 4deg$. Even if C is closed to a polyhedron by adding the convex polygonal base under C, this polyhedron can be edge-unfolded without overlap. The proof relies on some recently developed concepts, angle-monotone and radially monotone curves. The proof is constructive, leading to a polynomial-time algorithm for finding the edge-cuts, at worst $O(n^2)$; a version has been implemented.

János Pach and Géza Tóth: *A Crossing Lemma for Multigraphs*

Let G be a drawing of a graph with n vertices and $e > 4n$ edges, in which no two adjacent edgescross and any pair of independent edges cross at most once. According to the celebrated Crossing Lemma of Ajtai, Chvátal, Newborn, Szemerédi and Leighton, the number of crossings in G is at least $c\frac{e^3}{n^2}$, for a suitable constant $c > 0$. In a seminal paper, Székely generalized this result to multigraphs, establishing the lower bound $c\frac{e^3}{mn^2}$, where m denotes the maximum multiplicity of an edge in G. We get rid of the dependence on m by showing that, as in the original Crossing Lemma, the number of crossings is at least $c'\frac{e^3}{n^2}$ for some $c' > 0$, provided that the "lens" enclosed by every pair of parallel edges in G contains at least one vertex. This settles a conjecture of Kaufmann.

Sharath Raghvendra: *Optimal Analysis of an Online Algorithm for the Bipartite Matching Problem on a Line*

In the online bipartite matching problem, we are given a set S of server locations. Requests arrive one at a time, and on its arrival, we need to immediately and irrevocably match it to a server at a cost which is equal to the distance between these locations. A α-competitive algorithm will assign requests to servers so that the total cost is at most α times the cost of M_{opt} where M_{opt} is the minimum cost matching between S and R. In this paper, we consider this problem in the adversarial model where S and R are points on a line. We improve the analysis of the deterministic Robust Matching Algorithm (Nayyar and Raghvendra FOCS'17) from $O(\log^2 n)$ to an optimal $\Theta(\log n)$. Previously, only a randomized algorithm (under the weaker oblivious adversary model) achieves a $O(\log n)$ (Gupta and Lewi, ICALP'12) competitive ratio. The well-known Work Function Algorithm (WFA) has a competitive ratio of $O(n)$ and $\Omega(\log n)$ for the line metric. Therefore, WFA cannot achieve an asymptotically better competitive ratio than our algorithm.

Bruce Reed, Janos Pach and Yelena Yuditsky: *Almost All String Graphs are Intersection Graphs of Plane Convex Sets*

A string graph is an intersection graph of a family of continuous arcs in the plane. The intersection graph of any family of plane convex sets is a string graph, but not all string graphs can be obtained in this way. We prove the following structure theorem conjectured by Jansson and Uzzell: The vertex set of almost all string graphs on n vertices can be partitioned into five cliques such that some pair of them is not connected by any edge. We also show that every graph with the above property is an intersection graph of plane convex sets. As a corollary, we obtain that almost all string graphs on n vertices are intersection graphs of plane convex sets.

Oliver Roche-Newton: *An Improved Bound for the Size of the Set $A/A + A$*

It is established that for any finite set A of positive real numbers $|A/A + A| \gg |A|^{3/2+1/26}$. This improves a result of Shkredov.

Anastasios Sidiropoulos, Kritika Singhal and Vijay Sridhar: *Fractal Dimension and Lower Bounds for Geometric Problems*

We study the complexity of geometric problems on spaces of low *fractal dimension*. It was recently shown by [Sidiropoulos & Sridhar, SoCG 2017] that several problems admit improved solutions when the input is a pointset in Euclidean space with fractal dimension smaller than the ambient dimension. In this paper we prove nearly-matching lower bounds, thus establishing nearly-optimal bounds for various problems as a function of the fractal dimension. More specifically, we show that for any set of n points in d-dimensional Euclidean space, of fractal dimension $\delta \in (1, d)$, for any $\epsilon > 0$ and $c \geq 1$, any c-spanner must have treewidth at least $\Omega\left(\frac{n^{1-1/(\delta-\epsilon)}}{c^{d-1}}\right)$, matching the previous upper bound. The construction used to prove this lower bound on the treewidth of spanners, can also be used to derive lower bounds on the running time of algorithms for various problems, assuming the Exponential Time Hypothesis. We provide two prototypical results of this type:

- For any $\delta \in (1, d)$ and any $\epsilon > 0$, d-dimensional Euclidean TSP on n points with fractal dimension at most δ cannot be solved in time $2^{O\left(n^{1-1/(\delta-\epsilon)}\right)}$. The best-known upper bound is $2^{O(n^{1-1/\delta}\log n)}$.
- For any $\delta \in (1, d)$ and any $\epsilon > 0$, the problem of finding k-pairwise non-intersecting d-dimensional unit balls/axis parallel unit cubes with centers having fractal dimension at most δ cannot be solved in time $f(k)n^{O\left(k^{1-1/(\delta-\epsilon)}\right)}$ for any computable function f. The best-known upper bound is $n^{O(k^{1-1/\delta}\log n)}$.

The above results nearly match previously known upper bounds from [Sidiropoulos & Sridhar, SoCG 2017], and generalize analogous lower bounds for the case of ambient dimension due to [Marx & Sidiropoulos, SoCG 2014].

Jonathan Spreer and Stephan Tillmann: *The Trisection Genus of Standard Simply Connected PL 4-Manifolds*

Gay and Kirby recently introduced the concept of a trisection for arbitrary smooth, oriented closed 4-manifolds, and with it a new topological invariant, called the trisection genus. In this note we show that the $K3$ surface has trisection genus 22. This implies that the trisection genus of all standard simply connected PL 4-manifolds is known. We show that the trisection genus of each of these manifolds is realised by a trisection that is supported by a singular triangulation. Moreover, we explicitly give the building blocks to construct these triangulations.

Wai Ming Tai and Jeff Phillips: *Near-Optimal Coresets of Kernel Density Estimates*

We construct near-optimal coresets for kernel density estimate for points in $\mathbb{R}^d$ when the kernel is positive definite. Specifically we show a polynomial time construction for a coreset of size $O(\sqrt{d \log(1/\epsilon)}/\epsilon)$, and we show a near-matching lower bound of size $\Omega(\sqrt{d}/\epsilon)$. The upper bound is a polynomial in $1/\epsilon$ improvement when d in $[3, 1/\epsilon^2)$ (for all kernels except the Gaussian kernel which had a previous upper bound of $O((1/\epsilon)\log^d(1/\epsilon))$ and the lower bound is the first known lower bound to depend on d for this problem. Moreover, the upper bound restriction that the kernel is positive definite is significant in that it applies to a wide-variety of kernels, specifically those most important for machine learning.This includes kernels for information distances and the sinc kernel which can be negative.

Haitao Wang and Jingru Zhang: *An $O(n \log n)$-Time Algorithm for the k-Center Problem in Trees*

We consider a classical k-center problem in trees. Let T be a tree of n vertices and every vertex has a nonnegative weight. The problem is to find k centers on the edges of T such that the maximum weighted distance from all vertices to their closest centers is minimized. Megiddo and Tamir (SIAM J. Comput., 1983) gave an algorithm that can solve the problem in $O(n \log^2 n)$ time by using Cole's parametric search. Since then it has been open for over three decades whether the problem can be solved in $O(n \log n)$ time. In this paper, we present an $O(n \log n)$ time algorithm for the problem and thus settle the open problem affirmatively.

Jie Xue, Yuan Li, Saladi Rahul and Ravi Janardan: *New Bounds on Range Closest-Pair Problems*

Given a dataset S of points in $\mathbb{R}^2$, the range closest-pair (RCP) problem aims to preprocess S into a data structure such that when a query range X is specified, the closest-pair of points contained in X can be reported efficiently. The RCP problem can be viewed as a range-search version of the classical closest-pair problem, and finds applications in many areas. Due to its non-decomposability, the RCP problem is much more challenging than many traditional range-search problems. This paper revisits the RCP problem, and proposes new data structures for various query types including quadrants, strips, rectangles, and halfplanes. Both worst-case and average-case analyses (in the sense that the data points are drawn uniformly and independently from the unit square) are applied to these new data structures, which result in new bounds for the RCP problem. Some of the new bounds significantly improve the previous results, while the others are entirely new.

Conference Venue

Almost all talks, events will be held at Eötvös University's (ELTE) downtown campus in two buildings very close to each other: **Gólyavár** (main lecture rooms) and **Building B (room 172)**, address: Budapest, **Múzeum krt. 6-8**; A few events will be held at the **Rényi Institute**, address: **Reáltanoda utca 13-15**.

River Cruise, Tuesday, June 12 at 19:30

On Day 2, Tuesday, June 12, the evening event will be a **River Cruise** on the Danube. The departure location of the boat is **Port Akademia-3**. Please, be on time, by **19:30**! It is not trivial to find the exact port, and if you arrive after **19:30**, then you might not be able to board. The boat will arrive back to the port at around 22:00, and we have to leave it by 22:30.