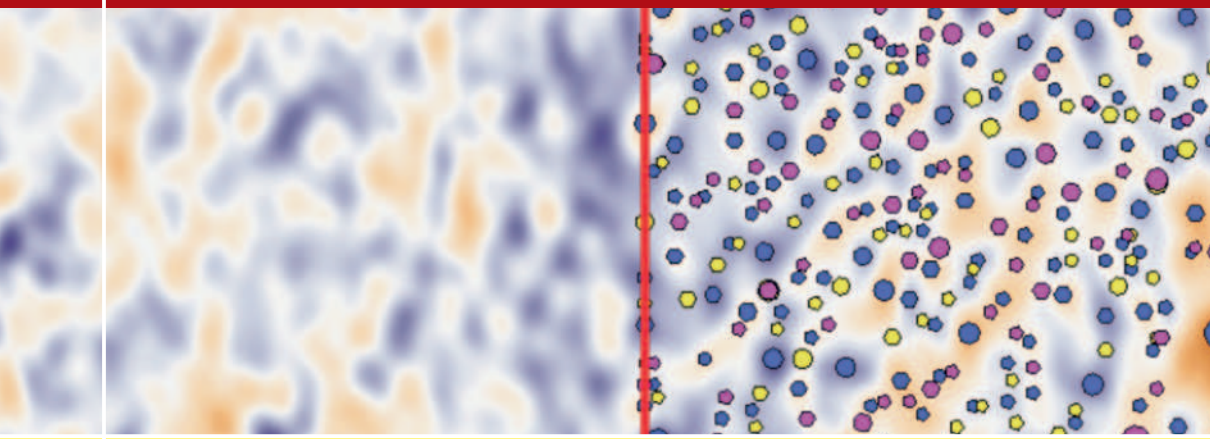
Mathematics and Visualization



Ingrid Hotz · Talha Bin Masood
Filip Sadlo · Julien Tierny *Editors*

Topological Methods in Data Analysis and Visualization VI

Theory, Applications, and Software

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Mathematics and Visualization

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Preface

Efficient analysis of large and complex data is playing a rapidly increasing role in essentially all scientific disciplines. Large amounts of data originate from diverse sources, e.g., simulations and experiments, and contain combinations of scalar, vector, or tensor data. Therefore, topology-based methods have gained increasing recognition also in context with visualization due to their robustness and rigorous mathematical guarantees. However, while reaching more and more applications, also novel challenges are developing continuously. These include increasing data complexity with respect to size and structures, multi-scale features, noise, and uncertainty. Developing efficient and robust numerical methods for specific applications and making them available to a large user base is another urgent demand.

The book is the 8th in a series based on the biannual TopoInVis workshops that aim for scientific exchange between researchers working in this field in an open atmosphere. The 8th workshop was held in Nyköping, Sweden, in June 2019 with a specific focus on software for topological data analysis and its applications. Most contributions in the book are related to or based on work that has been presented at the workshop. The book is structured into four parts. Part I focuses on topological methods for scalar fields and Part II focuses on more complex fields as vector, tensor, or multi-fields. Part III deals with topological methods for non-field data. Finally, Part IV reports the results from efforts trying to establish a community code bases for software development.

Part I focuses on theory and methods related to scalar field topology, followed by a couple of chapters on applications which demonstrate how theory translates into practical solutions to problems from diverse scientific domains. The first chapter discusses the W-structures in contour tree, algorithms for extraction of such structures, and their impact on the performance of distributed algorithms. It also demonstrates using an example that extended persistence is not equivalent to branch decomposition and leaf-pruning. The next chapter presents a novel interaction interface for exploring scalar fields using merge trees called *mergemaps*. The third chapter is an interesting discussion on application of graph theoretic concept of percolation analysis to scalar fields. With both Gaussian random fields and real data, it describes how the histogram or degree of structure influences the shape

of the percolation function. Then a chapter focuses on a discussion on implementing contour-tree-guided volume rendering of very large scalar field datasets in the context of in situ and distributed computing. The fifth chapter demonstrates how ideas from scalar field topology can be used for robust extraction and tracking of features in climate data. Multi-center cyclones are modeled as a set of critical points, and the tracking is done based on Morse complex. The last chapter of this part presents another application of scalar field topology in solving domain-specific problems, here the domain being astrophysics. It deals with design of contour-tree-guided feature extraction and visualization tool for analysis of image data obtained by current generation of radio and millimeter telescopes which are complex both in its spatial and spectral structures.

Part II contains contributions concerned with the analysis of fields with more complex attributes. The first three chapters deal with vector data. In the first chapter the notions of saddles, sinks, and sources originally defined for instantaneous vector fields are generalized to the finite-time setting based on a flow categorization with respect to contraction or expansion. The second chapter addresses the extraction of vortex corelines of inertial particles. Therefore, 3D and 6D parallel vector operators are introduced resulting in straight and bent inertial vortex corelines, respectively. In the following chapter it is shown how implicit visualization of 2D vector field topology can be used for periodic orbit extraction in 2D vector fields. The next two papers investigate fields with multiple attributes that shall be analyzed at the same time. The fourth chapter of this part applies visualization to evaluating a new topological equivalence relation, called *topological B+-equivalence* for the study of bounded bivariate fields. Invariants are introduced that approximate the equivalence. It is shown that visualizing the Reeb space gives us a near-instant way of evaluating these invariants. Topological relationships between multiple scalar fields to approach the analysis of time-varying multi-fields are considered in the next contribution. A novel method of finding similarity between two multi-fields by comparing their respective fiber component distributions is proposed. The Part II concludes with a chapter that deals with automatic chart analysis from rasterized images applying ideas from tensor field topology. It is demonstrated how positive semidefinite second-order tensor fields can be used as an effective model for this purpose.

Part III deals with topology-based methods for analysis of non-field data. It starts with a chapter that describes an approximate solution to the tree reconstruction problem for any finite point cloud in a Euclidean space with theoretical guarantees. The second chapter presents a novel approach for the extraction of micro-structural features called fibers from 3D scans of wood-based insulation materials. It describes how splitting geometry and topology processing of the data allows for topological simplification while still preserving the geometry of the scanned objects.

Part IV focuses on community efforts for developing the impact of topological methods in practice. It will particularly interest readers coming from the applications. It is composed of four chapters. The first chapter is a thorough introduction to vector field topology, which is an excellent entry point to any new comer to the field. The following three chapters are dedicated to the Topology ToolKit (TTK), an

open-source library for topological data analysis and visualization, which is a community-powered effort for making the research results of our community more accessible to the applications. The second chapter provides a global overview of the algorithms currently supported by TTK, including methods for scalar, bivariate, uncertain, and time-varying data. The following chapter describes with an example how TTK can be extended with the addition of a new module, dedicated in this illustration to the persistence-driven clustering of high-dimensional point cloud data. Finally, the last chapter provides experience feedback regarding the TTK hackathon organized in conjunction with TopoInVis 2019. It describes its organization and main results as well as reflections which spontaneously emerged then. It also provides detailed organizational pieces of advice which will be useful to anyone willing to organize a hackathon.

Lastly, we would like to mention that the 2019 TopoInVis Workshop was organized by the division of Media and Information Technology at Linkoping University. Here we would like to particularly acknowledge the support from Gun-Britt Löfgern in organizing the workshop and the social event. Further, we would like to acknowledge the financial support from the Swedish e-Science Research Center (SeRC). Naturally, we thank all the participants of the workshop for a successful event and the contributors to this collection of manuscripts. We also thank the diligent reviewers who helped immensely in improving the quality of the manuscripts during the two-phase review process. Special thanks goes also to Leonie Kunz for her help in the production process of this volume.

March 2021

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