A Hands-on TTK Tutorial for Absolute Beginners

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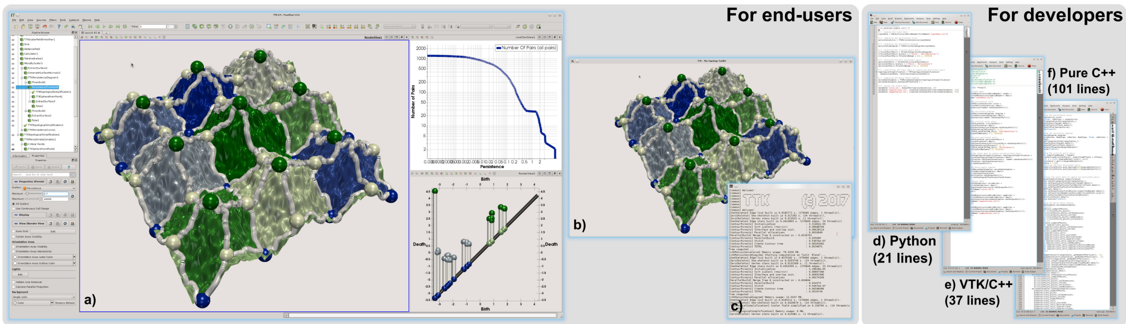

Figure 1: TTK is a software platform for topological data analysis and visualization. It is both easily accessible to end users (ParaView plugins (a), VTK-based generic GUIs (b) or command-line programs (c)) and flexible for developers (Python (d), VTK/C++ (e) or dependence-free C++ (f) bindings). TTK provides an efficient and unified approach to topological data representation and simplification, which enables in this example a Morse-Smale complex (a) to comply to the level of simplification dictated by a persistence diagram (bottom-right linked view, a). Code snippets are provided (d-f) to reproduce this pipeline.

1 Level of the Tutorial

This tutorial is targeted at a *Beginner* audience.

2 Potential Schedule Conflicts

If possible, we would like to avoid any scheduling overlap with IEEE LDAV 2023 and the IEEE TopoInVis 2023 workshop.

3 Abstract

This tutorial provides a basic, beginner's introduction to topological data analysis and visualization with the Topology ToolKit (TTK). **While previous editions of the TTK tutorial [12, 13, 15, 17, 18] (2018 to 2022) were organized as mini-symposia (focused on the descriptions of TTK's latest features), this year, in contrast, we would like to organize a very basic beginner's hands-on tutorial.** Specifically, the goal of this tutorial is to accompany attendees in the installation of TTK on their laptop as well as in the running of a few basic examples, all in a very beginner-friendly step-by-step description. This decision is motivated by attendee feedback which we collected at previous editions of the TTK tutorial. We address this feedback in this tutorial proposal. Then, for the first time, beginners would be able to come to the tutorial without prior TTK experience, and walk out with TTK installed on their system, capable of running a few examples and ready to go further. We believe this basic hands-on tutorial will facilitate the adoption of TTK and topological techniques to a broader audience.

The tutorial will be organized as follows. The first hands-on exercise will be dedicated to the installation of TTK. The second hands-on exercise will be focused on ParaView's basic usage. The following three hands-on exercises will be dedicated to the step-by-step replication of three examples extracted from TTK's online example database [57] (vortex extraction in fluid dynamics, Morse-Smale complex extraction in quantum chemistry and merge tree comparison in ensemble data).

We kindly ask potential attendees to optionally pre-register at the following address, in order for us to reach out to them ahead of the tutorial with information updates (for instance, last minute updates, instructions to download the tutorial material package, etc.): https://forms.gle/t4xX4a3pJjyiU67D9

Tutorial web page (data, material, schedule, etc.): https://topology-tool-kit.github.io/ieeeVisTutorial.html

4 Tutorial Organization

Motivations Topological analysis techniques [29, 42, 51] have shown to be practical solutions in various contexts: isosurface extraction [6, 45], feature tracking [48], volume rendering [62], data simplification [35, 55] and compression [49], similarity estimation [47, 56, 58], geometry processing [52, 60], data science [8, 10] or ensemble analysis [14, 31, 43, 44, 58]. They enable the concise and complete capture of the structure of the input data into high-level *topological data representations* such as persistence diagrams [11, 24, 59], contour trees [5, 20–22], Reeb graphs [23, 40, 41, 54], or Morse-Smale complexes [9, 26, 27]. Successful applications in a variety of fields of science have been documented (combustion [3, 25, 32], fluid dynamics [4, 7, 30, 37], material sciences [16, 28, 33], chemistry [1, 19, 38, 39], and astrophysics [46, 50]), which further demonstrates the importance of these techniques. While reference textbooks have been published [11], topological methods have not yet been widely adopted as a standard data analysis tool. We believe one of the reasons for this is the lack of open-source software that implements these algorithms in a generic, user-friendly, and efficient way. The Topology ToolKit (TTK) [2, 34, 53] has been released (BSD license) to fill this gap and 17 institutions have contributed to its development so far. This indicates that a user base exists and that further efforts towards the explanation of TTK's usage would be beneficial to the community.

Target audience This tutorial targets beginners (students, practitioners, or researchers) who have no prior experience with TTK or would like help to get started with TTK.

Tutorial goals The goal of this tutorial is to accompany attendees in the installation of TTK on their laptop as well as in the running of a few basic examples, all in a very beginner-friendly step-by-step description. Attendees would be able to come to the tutorial without prior TTK experience, and walk out with TTK installed on their system, capable of running a few examples and ready to go further.

Hands-on material The entire tutorial will be dedicated to detailed examples that the participants will be invited to reproduce. We will provide a rich material package, detailing in a step-by-step manner the installation of TTK, ParaView's basic usage as well as the running of a few basic examples extracted from TTK's online example database [57].

Optional pre-registration In previous editions, we observed that attendees would benefit from having time before the tutorial to download the tutorial material. If our proposal is accepted, we will use the following on-line form https://forms.gle/t4xX4a3pJjyiU67D9 to notify attendees about how to download the material and build a mailing list to help form an informal community for the tutorial.

Proposal strengths In contrast to previous tutorials on topological methods [61], we believe this proposal to have a unique concrete and applicative appeal, by its focus on the *usage* of topological methods rather than on their *foundations*. Thus, we expect it to attract a larger audience than the specific subset of IEEE VIS attendees typically found in traditional topology sessions. Moreover, in comparison to the previous editions of this tutorial, this year's edition will have a special emphasis on basic beginner's aspects, which we believe will facilitate the adoption of TTK and topological techniques to a broader audience.

Detailed content The tutorial is divided into two main parts (each part being subdivided into modules), for a target duration of approximately 3 hours. We plan for a 30-minute coffee break between the two main parts. However, this can be organized differently to fit any change in the coffee-break organization of IEEE VIS.

The first part of the tutorial (Sec. A, below) will cover the prerequisites for the hands-on exercises (Sec. B). Specifically, Sec. A will cover the core notions of Topological Data Analysis and it will illustrate them with concrete examples of data analysis tasks. A quick tour of ParaView will also be given, since it will be used as the main user interface for the hands-on exercises (Sec. B). Finally, Sec. A will also include (at the beginning) a session where participants will be invited to install TTK on their laptops.

The second part of the tutorial (Sec. B) will be dedicated to representative examples of data analysis pipelines. Specifically, it will cover three typical examples taken from TTK's online example repository [57]. These examples will illustrate how to: (1) extract points of interest in fluid dynamics (i.e. center of vortices), (2) extract a network of ridge lines in quantum chemistry (to represent molecular features such as carbon cycles or non-covalent interactions) and (3) compare datasets based on their topological description (by computing distances between merge trees).

A detailed outline of the program will be made available to tutorial participants on the tutorial webpage ahead of VIS 2023, but is omitted in this proposal for brevity. After the tutorial concludes, all content will be available on TTK's website.

A. Preliminaries (65 minutes)

A1. General introduction *(5 minutes)* This talk will provide an overview of the tutorial.

A2. Installing TTK *(20 minutes)* This first hands-on session will describe how to install TTK. Several options will be presented. The default option would be via the installation of Kitware's official ParaView distribution https://www.paraview.org/download/. Other options will be presented, such as Ubuntu packages, Anaconda packages or Docker images. At the end of this session, we expect all attendees to have TTK installed and running on their laptop.

A3. An introduction to Topological Data Analysis *(20 minutes)* This talk will cover the theoretical notions about Topological Data Analysis which are required for the followup step-by-step examples (Sec. B). Specifically, it will introduce: critical points, persistence diagrams, Reeb graphs, and Morse-Smale complexes. Also, it will illustrate how these notions can be used for data analysis.

A4. An introduction to ParaView's basic usage *(20 minutes)* This second hands-on session will describe the basic notions for using ParaView. The notion of pipeline browser will be presented, along with the properties and information panels for each filter of the pipeline. The different views will also be discussed. Screenshot features will be illustrated. Finally, pipeline IO will be presented (PVSM statefile) and Python exports will be illustrated.

B. A few step-by-step examples (85 minutes)

B1. Vortex extraction in fluid dynamics *(25 minutes)* This hands-on exercise will present the entry *Builtin Example 1* from TTK's online example database [57]. Then, we will describe to participants how to completely re-create this example from scratch.

B2. Morse-Smale complex computation *(25 minutes)* This hands-on exercise will present the entry *Persistent Generators AT* from TTK's online example database [57]. Then, we will describe to participants how to completely re-create this example from scratch.

B3. Merge tree comparison and matching *(25 minutes)* This hands-on exercise will present the entry *Merge Tree Feature Tracking* from TTK's online example database [57]. Then, we will describe to participants how to completely re-create this example from scratch.

B4. Concluding remarks *(10 minutes)* This talk will conclude the tutorial and discuss perspectives and current efforts.

5 Background and Contact Information

Christoph Garth – *garth@rptu.de* – is a professor of computer science at RPTU Kaiserslautern-Landau, and head of the scientific visualization group there. His research interests encompass the visualization and analysis of large scale data sets using methods from topological analysis, feature extraction, visual analytics, and high-performance computing, among others. In this context, he has employed TTK in teaching, to provide students with an in-depth understanding of topological methods, as well as for his research, as a robust and mature basis to develop novel visualization algorithms.

Robin Maack – *maack@rptu.de* – is a PhD student at the Scientific Visualization Lab at RPTU Kaiserslautern-Landau. He did his Master Studies in Computer Science at TU Kaiserslautern. His work focuses on algorithms and techniques in scientific visualization and computational topology. Through his work on Morse-Smale complex segmentation [36], he became a contributor for TTK.

Mathieu Pont – *mathieu.pont@sorbonne-universite.fr* – is a Ph.D. student at Sorbonne Universite. He received a M.S. degree in Computer Science from Paris Descartes University in 2020. His notable contributions to TTK include distances, geodesics, barycenters [43] and principal geodesic analysis [44] of merge trees.

Julien Tierny – *julien.tierny@sorbonne-universite.fr* – received the Ph.D. degree in Computer Science from the University of Lille in 2008. He is a CNRS senior scientist, affiliated with Sorbonne Universite. Prior to his CNRS tenure, he held a Fulbright fellowship and was a postdoc researcher at the SCI Institute at the University of Utah. His expertise includes topological data analysis and visualization. He is the lead developer of the Topology ToolKit (TTK).

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