

1 multipers : Multiparameter Persistence for Machine 2 Learning

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5 Summary

6 multipers is a Python library for Topological Data Analysis, focused on **Multiparameter**
7 **Persistence** computation and visualizations for Machine Learning. It features several efficient
8 computational and visualization tools, with integrated, easy to use, auto-differentiable Machine
9 Learning pipelines, that can be seamlessly interfaced with scikit-learn ([Pedregosa et al., 2011](#)) and PyTorch ([Paszke et al., 2019](#)). This library is meant to be usable for non-experts in
10 Topological or Geometrical Machine Learning. Performance-critical functions are implemented
11 in C++ or in Cython ([Behnel et al., 2011-03/2011-04](#)), are parallelizable with TBB ([Robison, 2011](#)), and have Python bindings and interface. It can handle a very diverse range of datasets
12 that can be framed into a (finite) multi-filtered simplicial or cell complex, including, e.g., point
13 clouds, graphs, time series, images, etc.
14
15

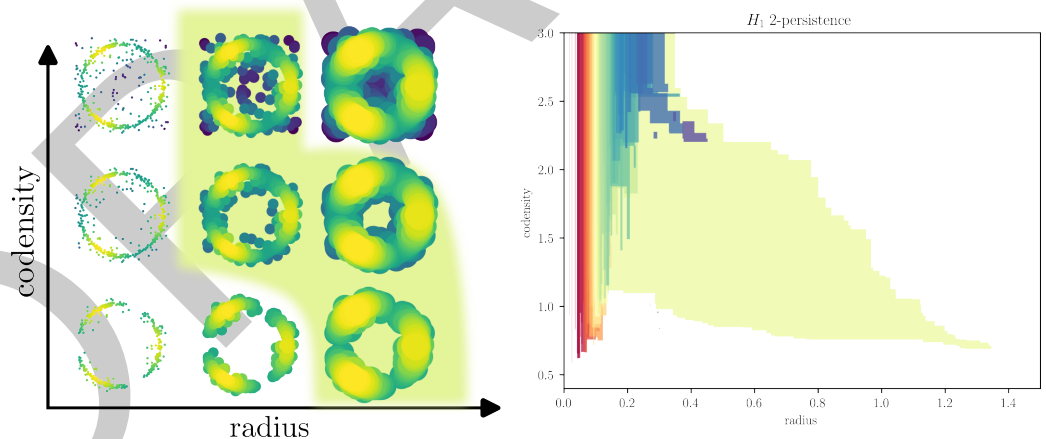


Figure 1: (Left) Topological 2-filtration grid. The color corresponds to the density estimation of the sampling measure of the point cloud. More formally, a point $x \in \mathbb{R}^2$ belongs to the grid cell with coordinates (r, d) iff $d(x, \text{point cloud}) \leq r$ and $\text{density}(x) \geq d$. The green background shape corresponds to the lifetime of the annulus in this 2-parameter grid. (Right) A visualization of the lifetimes of geometric structures given by multipers; here each colored shape corresponds to a cycle appearing in the bi-filtration on the left, and the shape represents its lifetime. The biggest green shape on the right is the same as the one on the left.

16 **Some motivation.** In the example of Figure 1, a point cloud is given from sampling a probability
17 measure whose mass is, for the most part, located on an annulus, with some diffuse background
18 noise. The goal here is to recover this information in a topological descriptor. For this, the
19 point cloud can be analyzed at some geometric scale $r > 0$ and density scale d by centering
20 balls of radius r around each point whose density is above d , and looking at the topology
21 induced by the union of balls. However, notice that neither a fixed geometric scale nor

density scale alone can retrieve (canonically) meaningful information due to the diffuse noise in the background; which is the main limitation of the prevalent approach. Nevertheless, by considering *all* possible combinations of geometric or density scales, also called a bi-filtration, it becomes straightforward with multipers to retrieve some of the underlying geometrical structures without relying on any arbitrary scale choice.

Furthermore, multipers seamlessly integrates several Rust and C++ libraries such as Gudhi (TheGudhiProject, 2023), filtration-domination (Alonso et al., 2023), mpfree (Kerber & Rolle, 2020), and function-delaunay (Alonso et al., 2024), and leverages on state-of-the-art Machine Learning libraries for fast computations, such as scikit-learn (Pedregosa et al., 2011), Python Optimal Transport (Flamary et al., 2021), PyKeops (Charlier et al., 2021), or PyTorch (Paszke et al., 2019). This makes multipers a very efficient and fully-featured library, showcasing a wide variety of mathematically-grounded multiparameter topological invariants, including, e.g., Multiparameter Module Approximation (Loiseaux et al., 2022), Euler, Hilbert, and Rectangle Signed Barcodes (Botnan et al., 2022) (Oudot & Scoccola, 2024), Multiparameter Persistent Landscapes (Vipond, 2020); each of them computable from several multi-filtrations, e.g., Rips-Density-like filtrations, Cubical, Degree-Rips, Function-Delaunay, or any k -critical multi-filtration. These topological descriptors can then directly be used in auto-differentiable Machine Learning pipelines, using the differentiability framework developed in (Scoccola et al., 2024), through several methods, such as, e.g., Decomposable Module Representations (Loiseaux, Carrière, et al., 2023), Sliced Wasserstein Kernels or Convolutions from Signed Measures (Loiseaux, Scoccola, et al., 2023). As a result, multipers is capable of handling, within a single minute of computation, datasets of $\sim 50k$ points with only 5 lines of Python code. See Figures 2, 3.

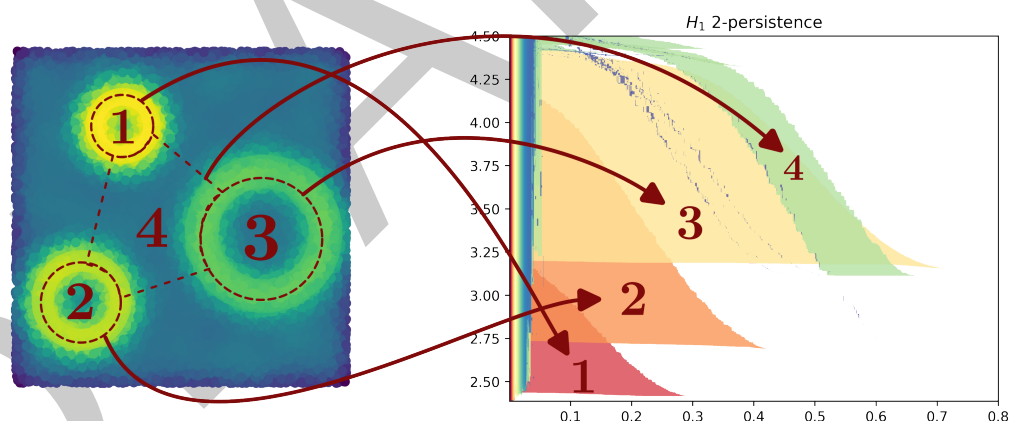


Figure 2: Typical interpretation of a “Geometric & Density” bi-filtration with multipers. **(Left)** Point cloud with color induced by density estimation (same as Figure 1). **(Right)** A visualization of the topological structure lifetimes computed from a Delaunay-Codensity bi-filtration; here the three cycles can be retrieved using their radii (x-axis) and their co-densities (y-axis). The first cycle is the densest, and smallest, and thus corresponds to the one that appears in the bottom(high-density)-left(small-radius) of the bi-filtration. The second is less dense (thus above the first one) and bigger (thus more on the right). The same goes for the last one.

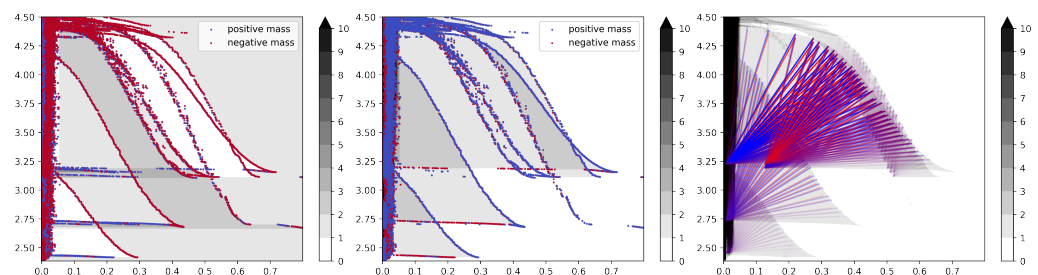


Figure 3: Different Signed Barcodes from the same dataset as Figure 1. **(Left)** Euler Decomposition Signed Barcode, and the Euler Surface in the background. **(Middle)** Hilbert Decomposition Signed Barcode, with its Hilbert Function surface. **(Right)** Rank invariant Signed Barcode, with the Hilbert Function as a background.

45 The core functions of the Python library are automatically tested on Linux and macOS, using
46 pytest (Krekel et al., 2004) alongside GitHub Actions.

47 Related work and statement of need

48 There exists several libraries for computation or pre-processing of very specific tasks related to
49 multiparameter persistence. However, to the best of our knowledge, none of them are able
50 to tackle the challenges that multipers is dealing with, i.e., (1) computing and unifying the
51 computations of multiparameter persistent structures, in a non-expert friendly approach, and
52 (2) provide ready-to-use general tools to use these descriptors for Machine Learning pipelines
53 and projects.

54 **Eulearning.** This library features different approaches for computing and using the Euler
55 Characteristic of a multiparameter filtration (Hacquard & Lebovici, 2023). Although relying
56 on distinct methods, multipers can also be used to compute Machine Learning descriptors
57 from the Euler Characteristic, i.e., the Euler Decomposition Signed Barcode, or Euler Surfaces.
58 Moreover, multipers computations are faster (especially on point cloud datasets), easier to
59 use, and available on a wider range of multi-filtrations.

60 **Multiparameter Persistent Landscape.** Implemented on top of Rivet (Lesnick & Wright,
61 2015), this library computes a multiparameter persistent descriptor by computing 1-parameter
62 persistence landscape vectorizations of slices in multi-filtrations (Vipond, 2020), called Multipa-
63 rameter Persistent Landscape (MPL). This library also features some multiparameter persistence
64 visualizations. However, it is limited to Rivet capabilities and landscapes computations, which
65 on one hand does not leverage on recently developed optimizations, e.g., (Alonso et al., 2023),
66 or (Kerber & Rolle, 2020), and on the other hand can only work with very specific text file
67 inputs.

68 **GRIL.** This library provides code to compute a specific, generalized version of the Multiparameter
69 Persistent Landscapes (Xin et al., 2023), relying on 1-paramter persistence zigzag computations.
70 This library however is limited to this invariant, can only deal with 2-parameter persistence, and
71 is not as much integrated as multipers with other multiparameter persistence and Machine
72 Learning libraries.

73 **Elder Rule Staircode.** This library features a descriptor for 2-parameter, degree-0 homology,
74 rips-density-like filtrations (Cai et al., 2021). Once again, this library is very specific and not
75 linked with other libraries.

76 **Persistable.** is a GUI interactive library for clustering, using degree-0 multiparameter persistence
77 (Scoccola & Rolle, 2023) (Rolle & Scoccola, 2020). Although aiming at distinct goals and
78 using very different approaches, multipers can also be used for clustering, by computing

(differentiable) descriptors that can be used afterward with standard clustering methods, e.g., K-means.

We contribute to this variety of task-specific libraries by providing a **general purpose** library, multipers, with novel and efficient topological invariant computations, integrated state-of-the-art Machine Learning topological pipelines, and interfaces to standard Machine Learning and Deep Learning libraries.

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