TOTOPO: Classifying univariate and multivariate time series with Topological Data Analysis

Polina Pilyugina, Rodrigo Rivera-Castro and Evgeny Burnaev

Skolkovo Institute of Science and Technology

Objectives

- Implement pipeline for **topological data analysis (TDA) for time series classification**
- Evaluate the performance on a broad range of datasets for time series classification
- Compare method to **topological baselines** and to **state-of-the-art approaches**

Innovation

- Approach compared to both baselines and **other TDA-based approaches**.
- Uses **sliding windows** and **direct extraction of Persistence Diagrams (PDs)**.
- **Combines models** as an **ensemble**.

TOTOPO

1. Create PDs from time series.
2. Calculate **TDA inputs** from PDs: **Betti series, TDA Summaries and L^2-norms series**.
3. Train **base learners** on inputs and the original time series.
4. Generate an **ensemble of base learners**.

Multivariate time series results

TOTOPO works with **both univariate and multivariate** time series.

- TOTOPO is **the second best performer** compared to two baselines and a novel SOTA by Franceschi, [1].
- On the 4-channel dataset ERing TOTOPO **improves accuracy** from an average of 13.3% up **to 94.4%**.

Univariate time series results

- TOTOPO is **the third best classifier**, as suggested by CD diagram, on **78 univariate datasets** from [2].
- TOTOPO **outperforms all models** on 5 out of 6 datasets of type **DEVICE**.

Limitations: TOTOPO underperforms on datasets with **small differences between classes**.

Schematic Model Description and CD Diagram

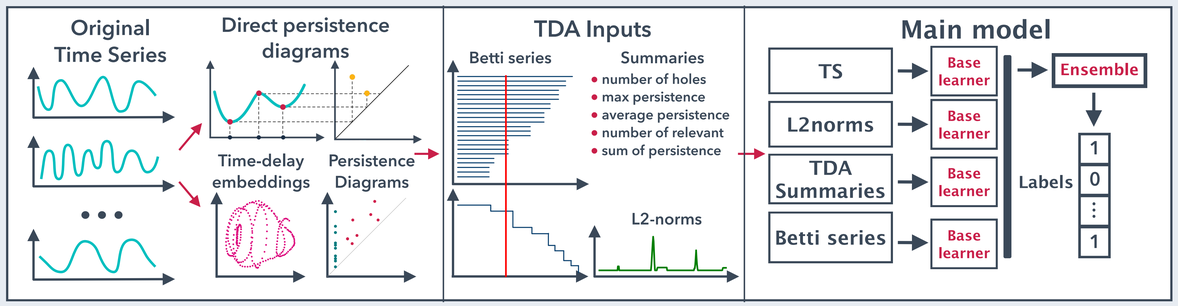

Figure: Schematic model description.

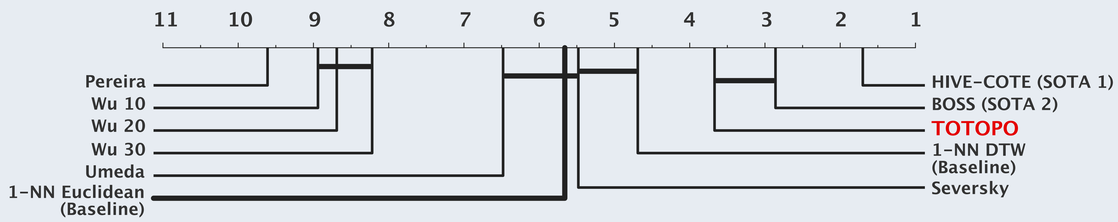

Figure: CD diagram with black horizontal lines showing statistically similar classifiers.

Noise robustness exploration

- **Apply three noise levels** to the signals.
- Compare **average accuracies** for each noise level on Figure 3.
- **TOTOPO's accuracy deteriorates less** then others for small noise levels.

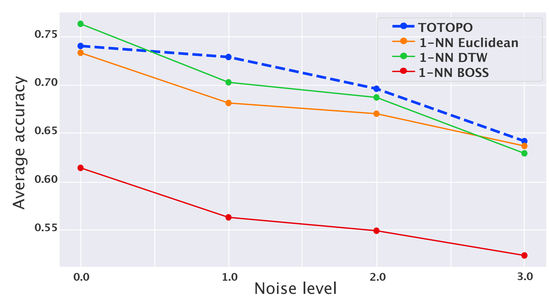

Figure: Comparison of different algorithms' performances for different noise levels

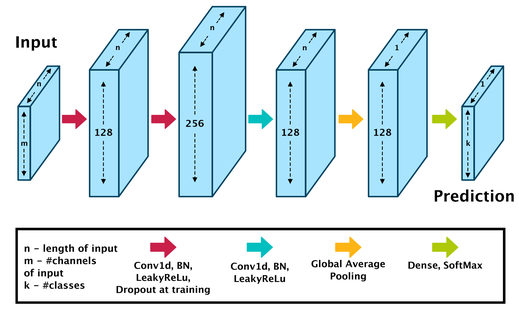

Figure: Overview of the structure of the base learner classifier.

References

[1] J.-Y. Franceschi and M. Jaggi, "Unsupervised Scalable Representation Learning for Multivariate Time Series," tech. rep., 2020.

[2] A. Bagnall, J. Lines, A. Bostrom, J. Large, and E. Keogh, "The great time series classification bake off: a review and experimental evaluation of recent algorithmic advances," *Data Mining and Knowledge Discovery*, vol. 31, pp. 606–660, may 2017.

[3] R. Rivera-Castro, A. Pletnev, P. Pilyugina, G. Diaz, I. Nazarov, W. Zhu, and E. Burnaev, "Topology-Based clusterwise regression for user segmentation and demand forecasting," in *2019 IEEE International Conference on Data Science and Advanced Analytics (DSAA)*, pp. 326–336, Oct. 2019.

[4] M. Gidea, D. Goldsmith, Y. Katz, P. Roldan, and Y. Shmalo, "Topological recognition of critical transitions in time series of cryptocurrencies," pp. 1–29, 2018.

For more information:

Skoltech

Skolkovo Institute of Science and Technology