




Pycrostates: a Python library to study EEG microstates

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Summary

Microstate analysis of the electroencephalogram (EEG), introduced in 1972 by Lehman ([Lehmann, 1971](#)), is a spatiotemporal analysis technique that takes advantage of the full spatial resolution of EEG recordings. Formalized further by Pascual Marqui and colleagues ([Pascual-Marqui et al., 1995](#)), microstate analysis studies the distribution of the surface EEG potential maps over time. It transforms the EEG recordings into sequences of successive states of variable duration, called EEG microstates.

Pycrostates implements multiple modules that allow researchers to apply microstate analysis on their datasets:

- the cluster module supports the different clustering algorithms that find the optimal topographic maps that sparsely represent the EEG.
- the segmentation module supports the study of microstates sequences and their summary measures.
- the metrics module quantifies the quality of the fitted clustering algorithms.

Additional modules help researchers to develop analysis pipelines:

- the dataset module provides direct access to preprocessed data that can be used to test pipelines. As of writing, it supports the LEMON dataset ([Babayan et al., 2019](#)) comprising preprocessed EEG recordings of 227 healthy participants.
- the viz module provides visualization tools for performing microstate analyses.

By design, Pycrostates is not restricted to EEG data. Its API is build on top of the robust MNE-Python ([Gramfort, 2013](#)) ecosystem enabling a seamless integration of microstates analysis. It's modular design supports all data types from MNE-Python and future improvements and additions such as different clustering algorithms or new tools for sequences analysis such as Markov chains.

Statement of need

Currently, several software and libraries are available to perform EEG microstates analysis: Cartool ([Brunet et al., n.d.](#)), Thomas Koenig's MATLAB microstates EEGLab toolbox (<https://www.thomaskoenig.ch/index.php/software/microstates-in-eeqlab>), or Andreas Trier Poulsen's MATLAB microstates EEGLab toolbox ([Poulsen et al., 2018](#)). In the last few years, the Python programming language ecosystem has expanded considerably, especially in scientific fields. MNE-Python ([Gramfort, 2013](#)) stands out for the analysis of human neurophysiological

data. Current Python implementations of microstate analysis include the Python 2 library from Frederic von Wegner (Wegner & Laufs, 2018), Neurokit (Makowski et al., 2021), KeyPy (Milz & Gnatenko, 2016) (no longer maintained) and the MNE-microstates package from Marijn van Vliet.

However, the current implementations of microstates analysis have a limited number of features and/or are not maintained on a regular basis. Most of them perform the microstate segmentation at the subject level while computation of microstates topographies and segmentations at the group level are not covered. Pycrostates is based on the robust MNE-Python ecosystem and complements it with simple tools for developing integrated microstates analysis pipelines. It offers flexible classes, enabling group level analysis and advanced segmentation features such as smoothing and small segment rejection which are especially useful for handling low signal to noise datapoints occurring during microstate polarity inversions.

Pycrostates API supports most of the analyses proposed in the literature (Michel & Koenig, 2018) and in standard but non-Python packages such as Cartool (Brunet et al., n.d.) or MATLAB microstates EEGLab toolboxes. Pycrostates is built with a modular and scalable design, following modern development methods and standards to facilitate its maintenance and evolution over time. It offers a solid basis to the open source community to use microstate methodology and to make it evolve. Finally, new users will benefit from the exhaustive documentation and tutorials describing microstate analysis.

With this contribution, the developer team is excited to provide the state-of-the-art in microstates analysis and is looking forward to welcoming new contributors and users from the broader MNE, neuroscience, and electrophysiology communities.

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