PyBispectra

An open-source toolbox for advanced electrophysiological signal processing based on the bispectrum

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BACKGROUND

- Phase-amplitude coupling, time delays, and non-sinusoidal waveform features provide insights into neuronal function and dysfunction.
- Common methods for these analyses possess notable limitations.
- The bispectrum – the Fourier transform of the third order moment – can quantify these features without many of the limitations.
- We present PyBispectra, an open-source Python-based toolbox for analysing electrophysiological signals using the bispectrum.

The bispectrum has the fundamental form

$$\mathbf{B}_{kmn}(f_1, f_2) = < \mathbf{k}(f_1)\mathbf{m}(f_2)\mathbf{n}^*(f_2 + f_1) >$$

where $\mathbf{B}$ is the bispectrum; kmn is a combination of signals with Fourier coefficients $\mathbf{k}$, $\mathbf{m}$, and $\mathbf{n}$, respectively; f_1 and f_2 correspond to a lower and higher frequency, respectively; and <> represents the average value over epochs.

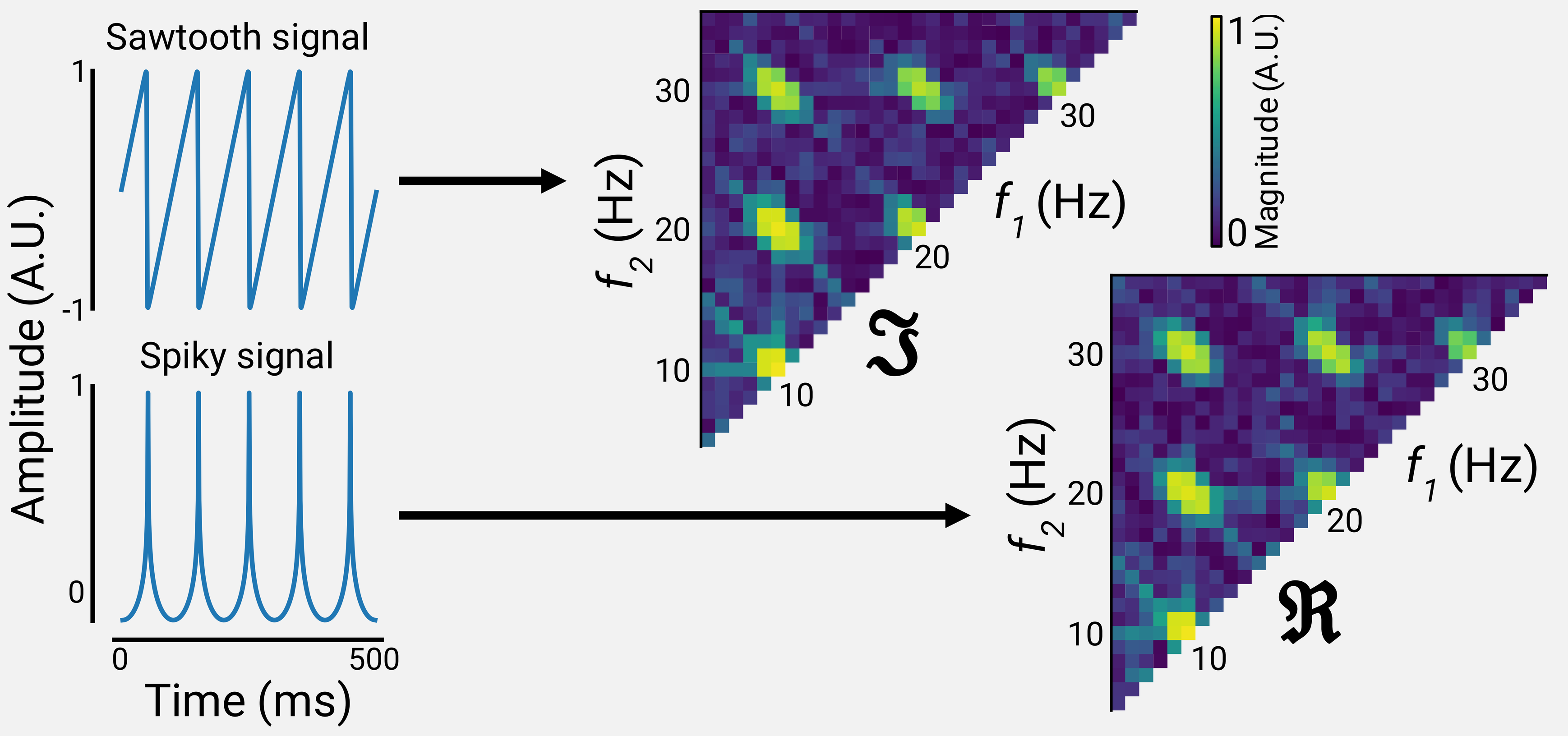
USE CASE: WAVESHAPE ANALYSIS [1]

Motivation: non-sinusoidal features reflect synaptic input synchrony and are biomarkers of neurological disorders.

Common method: time-series analysis – necessary preprocessing steps (e.g. bandpass filtering) can corrupt underlying signal shape; computationally expensive for high sampling rate data.

Bispectrum: extracts information about sawtooth (rise-decay asymmetry) and spike (peak-trough asymmetry) characteristics - provides a frequency-resolved result (no need to bandpass); computationally cheap, even for high sampling rate data.

Example: non-sinusoidal features at 10 Hz and harmonics



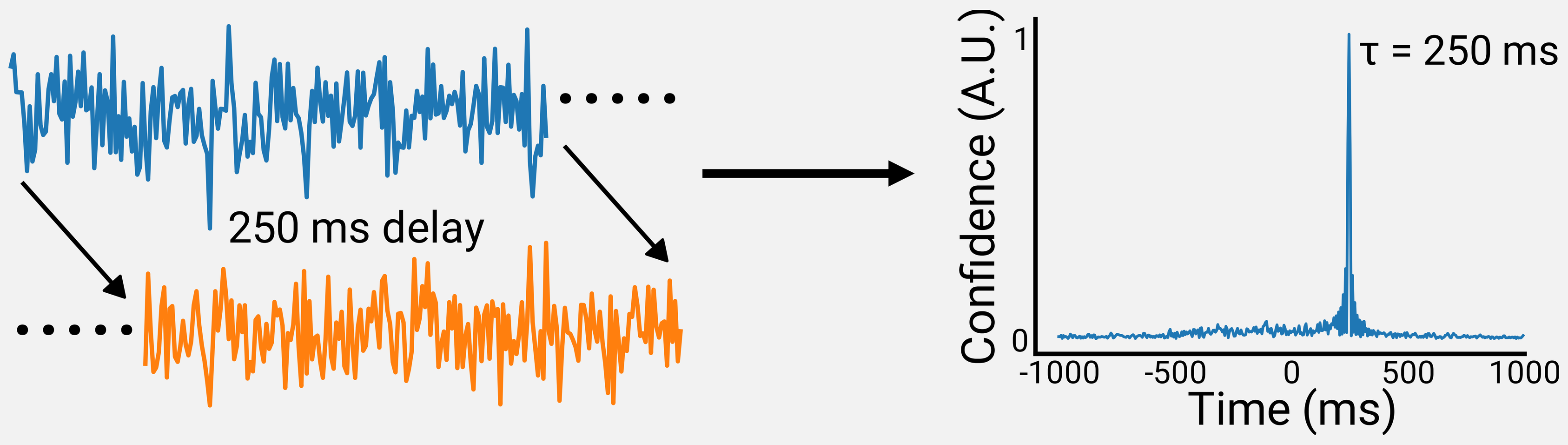
USE CASE: TIME DELAY ESTIMATION [2, 3]

Motivation: reflects the physical connections between brain regions.

Common method: cross-correlation – compromised by volume conduction.

Bispectrum: immune to volume conduction artefacts with antisymmetrisation.

Example: time delay estimation at 250 ms



Easy-to-use, with simple syntax

Detailed API documentation and in-depth tutorials

High performance, with low-level source code compilation and support for parallel processing

Check out the toolbox:

pybispectra.readthedocs.io

PyBispectra Pipeline

0. Preprocessing (Optional)

```
from pybispectra import SpatioSpectralFilter
```

Enhance the signal-to-noise ratio for a frequency band of interest.

1. Compute Frequency Information

```
from pybispectra import compute_fft, compute_tfr
```

Compute the (time-)frequency representation of data.

2. Compute Results

```
from pybispectra import PAC, PPC, AAC, TDE, WaveShape
```

Support for cross-frequency coupling (phase-amplitude, phase-phase, amplitude-amplitude), time delay estimation, and waveshape analysis.

Example Code (Phase-Amplitude Coupling)

```
coeffs, freqs = compute_fft(data, sampling_freq)
pac = PAC(coeffs, freqs, sampling_freq)
pac.compute()
pac_results = pac.results
pac_results.plot()
```

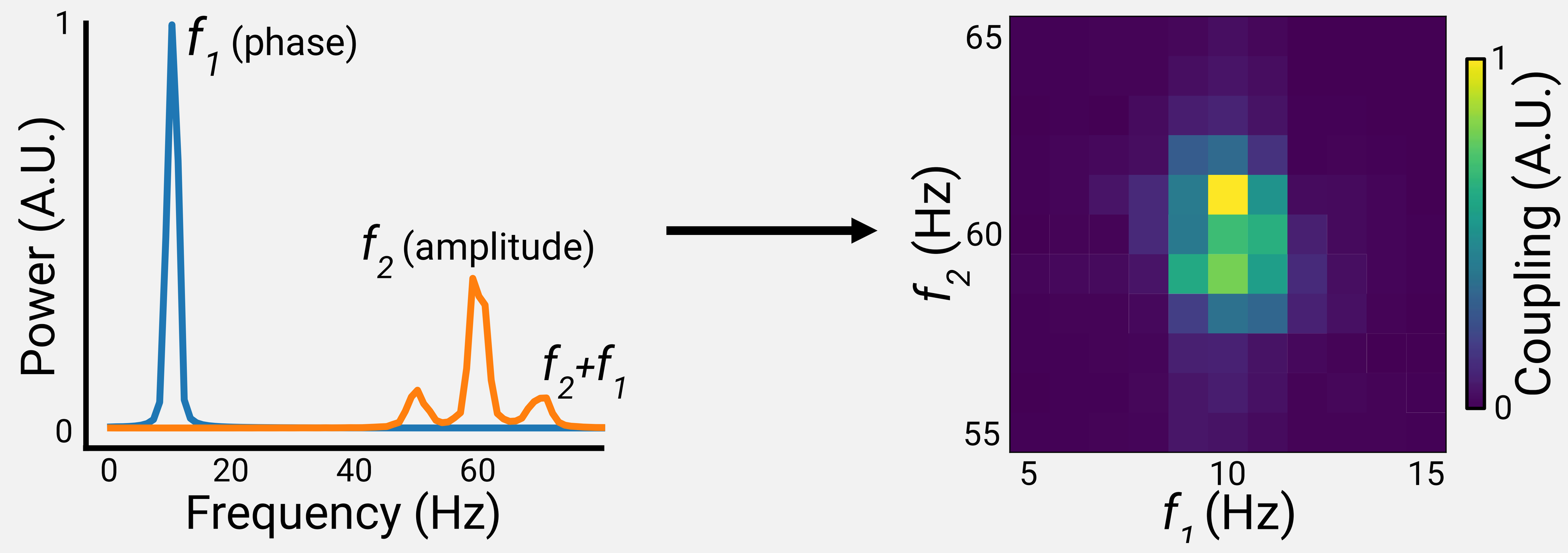
USE CASE: PHASE-AMPLITUDE COUPLING [4, 5]

Motivation: mechanism for integrating information between neuronal systems across spatiotemporal scales, disrupted in neurological disorders.

Common method: modulation index – requires the use of precise, difficult to find filters; relies on the computationally-expensive Hilbert transform; compromised by volume conduction.

Bispectrum: no filters required; relies on the computationally-cheap Fourier transform; immune to volume conduction artefacts with antisymmetrisation.

Example: 10-60 Hz phase-amplitude coupling



References: [1] Bartz *et al.* (2019). Analyzing the waveshape of brain oscillations with bicoherence. *NeuroImage*; [2] Nikias & Pan (1988). Time delay estimation in unknown Gaussian spatially correlated noise. *IEEE Transactions on Acoustics, Speech, and Signal Processing*; [3] Jurhar *et al.* (In Preparation). Estimating signal time-delays under mixed noise influence with novel cross- and bispectrum methods; [4] Zandvoort & Nolte (2021). Defining the filter parameters for phase-amplitude coupling from a bispectral point of view. *Journal of Neuroscience Methods*; [5] Pellegrini *et al.* (In Preparation). Distinguishing across- from within-site phase-amplitude coupling.

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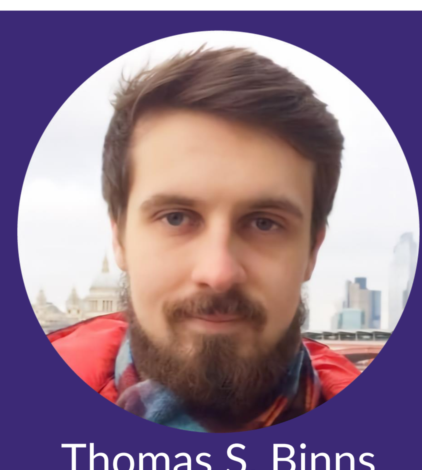

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