CEA NeuroSpin, INRIA & INSERM ENS Lyon CNRS

http://www.ens-lyon.fr/PHYSIQUE/Equipe3/MultiFracs/

Multivariate Multifractal Analysis of Human Brain Dynamics in Magnetoencephalography (MEG)

Research theme: statistical signal processing, MEG, EEG, cognitive neuroscience.

Duration: 1 year (salary commensurate with experience).

Teams: CEA/NeuroSpin (INRIA Parietal & INSERM) & (SISYPHE, CNRS/ENS Lyon).

Advisors: Philippe Ciuciu (philippe.ciuciu@cea.fr, +33 1 6908 7785) and Patrice Abry (patrice.abry@ens-lyon.fr, +33 4 72728493).

Collaborator: Virginie van Wassenhove (virginie.van.wassenhove@gmail.com, CEA/NeuroSpin & INSERM) for applications in cognitive neurosciences.

Location: The candidate will be hired by ENS Lyon through the ANR Multifracs project and located at ENS Lyon and/or at NeuroSpin Saclay, depending on scientific developments.

Application: Interested candidates should send their CV, a motivation letter and at least 2 references.

Research topic: The Human brain is a complex biological system endowed with cognitive complexity. A sound interfacing between cognitive neuroscience and sophisticated quantification of complex systems requires the elaboration of signal processing techniques providing explanatory power for the functional description of neural systems. In this context, the renewed interest in *scale-free* neural activity has been sparked by several lines of evidence: first, ongoing neural oscillations recorded in the resting brain have a deterministic impact on the neural responses evoked by the presentation of stimuli [**Thivierge08**; **Sadaghiani09**]. Second, the interregional coherence of activity fluctuations (or functional connectivity) in the resting brain is commensurate with the synchronization of low frequency neural oscillations (< 2 Hz) namely, the scale-free portion of the power spectrum. Third, scale-free descriptions of neural activity are correlated with the scale-free quantification of behavioral outcomes [**Monto08**]. These converging evidence for the importance of scale-free properties in neural systems have been observed with various functional neuroimaging techniques such as functional magnetic resonance imaging (fMRI) [**Ciuciu12**; **Ciuciu14**] or magnetoencephalography (MEG) [**Zilber14**; **LaRocca_JNM_18**]. This line of research is not without major challenges: functional neuroimaging data are noisy, multivariate, organized in complex networks. As such, novel statistical signal processing methods are necessary and we contend that the multifractality approach as well as some dedicated measure of functional connectivity operating in the scale-free regime provide promising venues.

In the last decade, multifractal analysis has received significant appeal in the mathematics and signal processing communities. In particular, the Leader-based Multifractal (WLMF) framework [**Wendt07**; **Wendt09**] has emerged as the most accurate strategy for characterizing univariate scale-free time series. Using the WLMF formalism, we showed that MEG activity displays refined modulations of scale-free properties that are functionally meaningful in the context of learning and plasticity. Notably, a post-training decrease of long memory and an increase in multifractality were observed suggesting the existence of mesoscopic biomarkers of functional plasticity [**Zilber14**; **LaRocca_sub2JN_19**]. Concomitantly, the weighted Phase Lag Index (wPLI) has emerged as one of the most robust quantification of phase synchronization in M/EEG time series [**Vinck2011**]. Although the wPLI measure is currently used in oscillatory frequency regimes (α, β, γ), we have recently extended its definition in the wavelet domain to deal with the scale-free regime [**LaRocca_EUSIPCO18**] and thus propose a *fractal connectivity estimator*. On the above mentioned MEG database, the wavelet-based wPLI measure has allowed to uncover modifications of functional connectivity induced by training.

Work plan. The goal of the project is to perform multivariate scale-free analysis of MEG data. 30 healthy individuals performing a timing task will be recorded with MEG. The experimental protocol was conceived in collaboration with the Cognition & Brain Dynamics team (Dir: V. van Wassenhove) as an extension of recent work (see [**Polti2018**] for the general context in experimental psychology; see [**Kononowicz2019**] and [**Grabot2017**] for the neuroscientific aspects).

Two main analytical tracks will be explored using scale-free indices:

- **Multivariate self-similarity.** Based on a recently devised multivariate self-similarity model, a multivariate procedure for the joint estimation of Hurst parameters has been assessed [**AbryDidier2018**]. The latter will be applied to MEG source estimates collected during rest and during timing. The co-existence of distributed Hurst exponents will be used as a proxy for the number of *independently activated* neural sources (following our recent working hypothesis elaborated in [**LaRocca_JNM_18**]). The joint estimation procedure will be applied to MEG time series, and also tested on the envelope of the signals (following Hilbert transform) in oscillatory regimes.
- **Multivariate multifractality.** The multivariate multifractal formalism proposed in [**jaffard2018acha**] enables to quantify dependencies between time series at higher statistical orders, i.e., beyond cross-correlation. This framework will be used to construct a new index of functional connectivity between remote brain regions. As for self-similarity, these tools will be applied to MEG time series and to the envelope of oscillatory activity to test several means of constructing functional connectivity indices.
- **Implementation & interpretation.** The candidate will implement data analysis in collaboration with the different members of the consortium using a dedicated Python package (univariate multifractal analysis[1]). Statistical analyses will be performed at the group-level using the MNE-Python software.

Skills. Candidates strongly motivated by exploratory and multidisciplinary research topics, with relevant background in statistical signal processing, wavelet theory and/or cognitive neuroscience will be appreciated. Skills in and practice of `Python` and `Matlab` are expected as well as preliminary experience with time-resolved neuroimaging data analysis.

Keywords. Statistical signal processing, scale-free, 1/f, MEG, EEG, timing, time perception, Python, mne-python.

[1] https://github.com/neurospin/mfanalysis