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Detecting clusters of synchronized oscillators in the presence of large colored noise

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Over the last two decades, singular spectrum analysis (SSA) has became widely used in the identification of intermittent or modulated oscillations in geophysical and climatic time series; for an overview, see Ghil et al. (Rev. Geophys., 2002). SSA decomposes the delay-coordinate phase space of a given time series into a set of data-adaptive orthonormal components and allows one to reconstruct a robust "skeleton" of the dynamical system's structure and dynamics.

Groth and Ghil (Phys. Rev. E, 2011) have recently demonstrated that multivariate SSA (M-SSA) greatly helps identify and track phase synchronization in a large system of coupled oscillators and in the presence of high observational noise levels. With no need for detailed knowledge of individual subsystems nor any a priori phase definition for each of them, M-SSA is able to automatically identify multiple oscillatory modes and detect whether these modes are shared by clusters of phase- and frequency-locked oscillators. Even if the oscillatory behavior is getting swamped by the observational noise — e.g. in the presence of additive white noise of the same variance as the dynamical system — M-SSA gives robust and reliable results.

In many geophysical problems, however, the irregular, noisy part exhibits weak temporal correlations and doesn't match the assumption of white noise. For this reason, Allen and Smith (J. Climate, 1996) proposed an SSA Monte Carlo test against a colored-noise null hypothesis in order to distinguish regular behavior from random fluctuations. This test was originally designed for a univariate SSA and its application to M-SSA becomes less and less discriminating as the number of variables increases.

In this talk, we present a modified M-SSA Monte Carlo test that allows for the detection of irregular oscillations in the presence of colored noise even in higher-dimensional time series. We show that the concept of Procrustes target rotation helps one to overcome the dimensionality problem in the matching of M-SSA results from the time series and M-SSA results from the null hypothesis' surrogate data. Moreover, this concept provides significance levels not only for the M-SSA eigenvalues but also for the corresponding eigenvectors.

As already shown by Groth and Ghil (Phys. Rev. E, 2011), a suitably defined function of an eigenvalue and the associated eigenvector yields a participation index for each of the time series in a detected cluster. The M-SSA Monte Carlo test proposed here thus further facilitates the significance analysis of phase synchronization in time series.