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A new measure for the detection of directional couplings based on rank statistics

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We introduce a new technique designed to quantify directional couplings between nonlinear dynamics and we evaluate its application to the study of neuronal data. Similar to existing approaches [1,2] (and references therein) this technique quantifies the degree to which similar states of the one dynamics are mapped to similar states of the other dynamics based on reconstructed state-spaces. It differs from these existing techniques in that it uses rank statistics instead of distance statistics.

We illustrate the advantages of this approach by comparing it to measures based on distance statistics [1,3,4] in application to model systems under controlled conditions. Specifically we study linear stochastic processes, low dimensional oscillators and high dimensional dynamical systems with time-delays to characterize the new measure. The new measure is normalized to one for identical synchronization, and we show that it is symmetrically distributed around zero for independent linear stochastic processes. In contrast, existing approaches can produce a bias and erroneously indicate directional couplings where this bias depends on the strength of the autocorrelation of the respective linear stochastic processes. Furthermore we show that the measure based on the rank statistics is more reliable extracting the coupling direction for deterministic dynamics, while some measures using distance statistics can be misled by different degrees of complexity of the respective dynamics.

Furthermore we study interactions between neuronal signals. We analyze pairs of intracranial electroencephalographic recordings from rats [4] and intracranial electroencephalographic recordings from the seizure-free interval of epilepsy patients [5]. In both cases these recordings have been previously studied with regard to the detection of couplings from experimental signals [4,5]. We show that the directional couplings quantified by our new measure agree with results reported in these previous studies. Furthermore, first results indicate that also in these applications our approach is robust in extracting consistent coupling directions.

In summary, we show, based on studies of mathematical model systems, that our approach is more robust in extracting the correct coupling direction in various settings. We currently extend our analysis to different types of neuronal recordings and expect that the advantages seen under controlled conditions also hold for these experimental recordings.

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