A Bayesian State-Space Approach to Mapping Directional Brain Networks

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Abstract: The human brain is a directional network system of brain regions involving directional connectivity. Seizures are a directional network phenomenon as abnormal neuronal activities start from a seizure onset zone (SOZ) and propagate to otherwise healthy brain regions. To localize the SOZ of a patient with drug-resistant epilepsy, clinicians use intracranial EEG (iEEG) to record the patient's neuronal activity inside the skull. iEEG data are high-dimensional multivariate time series recordings of neuronal activities in many small brain regions. We build a state-space multivariate autoregression (SSMAR) for iEEG data to model the underlying directional brain network system. We identify connected brain regions (i.e., mapping the brain network) through estimating the SSMAR parameters that denote directional connectivity. To increase model estimation efficiency and to produce scientifically interpretable network results, we incorporate into SSMAR the scientific knowledge that the underlying brain network tends to have a cluster structure. Specifically, we assign to the SSMAR parameters a stochastic-blockmodel-motivated prior reflecting the cluster structure. In contrast to most existing network models that were developed mainly for observed network edges, we develop a Bayesian framework to estimate the proposed high-dimensional model, infer directional connections, and identify clusters for the unobserved network edges. We show through both simulation and real data analysis that the new method is robust to various deviations from the model assumptions and outperforms existing network methods. Applying the developed SSMAR and Bayesian approach to an epileptic patient's iEEG data, we reveal the patient's network changes during seizure development and the unique connectivity property of the SOZ.