Quantifying Information Dynamics in CNS Networks

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Abstract We present a generically applicable four-step process for quantifying information movement in complex networks. (1) Construction of local entropy rate and specific entropy rate. Local entropy rate is a continuous, time-dependent measure that quantifies the information gained at time t on observing $x(t)$ given the recent past. There is a statistically responsible procedure for specifying "recent". Specific entropy rate is a related time-dependent locally determined measure that gives an estimate of uncertainty at time t. (2) Construct specific transfer entropy (i.e., a time-dependent generalization of epoch-determined transfer entropy) that gives a state- and time-resolved quantification of the predictive input of a candidate input system on a candidate output system. (3) Construct a time-dependent network adjacency matrix. Specific transfer entropy can be used to populate the adjacency matrix characterizing a network. In the case of multichannel EEG/MEG recordings, the nodes are electrodes, and specific transfer entropy quantifies information movement between electrodes. In this analysis, the adjacency matrix is real, time-dependent and asymmetric. Any of a large number of measures commonly used to characterize an adjacency matrix can be used. The result $\Lambda(t)$ is a scalar function of time. (4) Identify hierarchical transition chronometries in $\Lambda(t)$. The simple directive "find transitions in $\Lambda(t)$" is unacceptably naive. Dynamically meaningful transitions are timescale-dependent. In this analysis, $\Lambda(t)$ is embedded and the structure of this embedded object is examined by quadrant scans of the corresponding recurrence diagram. A hierarchy of transitions can be identified by manipulating the embedding dimension.

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We note that $\Lambda(t)$ can serve as the order parameter in phase transition experiments in which time is the tuning parameter.