Uncovering Dynamical States Through Concurrent Electroencephalography (EEG) and Electrocorticography (ECoG)

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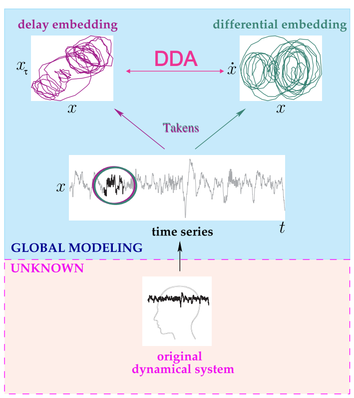
Abstract

Using tailored brain structural network models, a recent study (Bansal et al., 2019) has shown that chimera states (coexisting domains of synchrony and asynchrony) formed across different brain regions play a crucial role in the cognitive organization of the human brain. To further investigate these states as well as their roles in large-scale brain function, the present study examines the spatio-temporal dynamics of chimera states in simulated networks as well as in concurrent EEG/ECoG recorded from patients with epilepsy, using delay differential analysis (DDA; Lainscsek et al., 2013). Due to their high spatial and temporal resolution, concurrent EEG/ECoG data allow us to examine not only the spatio-temporal dynamics throughout the brain, but also the directions of information flows between different brain regions.

Delay Differential Analysis (DDA)



DDA is based on Delay Differential embedding:

differential embedding

delay embedding

$$\frac{\mathrm{d}x(t)}{\mathrm{d}t} = f(a, x(t-\tau_1), x(t-\tau_2), \ldots)$$

DDA is computed in the **time domain** and not in the spectral domain

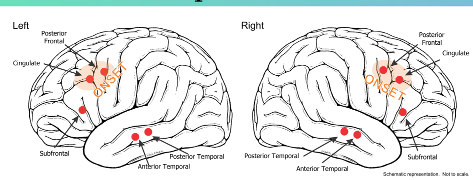
⇒ coefficients a_k and least square error as features

Here, we use the model:

$$\dot{x} = a_1 x_1 + a_2 x_2 + a_3 x_1^4,$$

$x_i = x(t-\tau_i)$ and $\boldsymbol{\tau} = (7, 10)\ \delta t$, where $\delta t = \frac{1}{f_s}$ with $f_s = 500$ Hz.

Locations of the implanted ECoG electrodes



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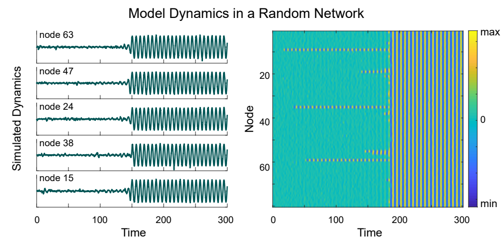
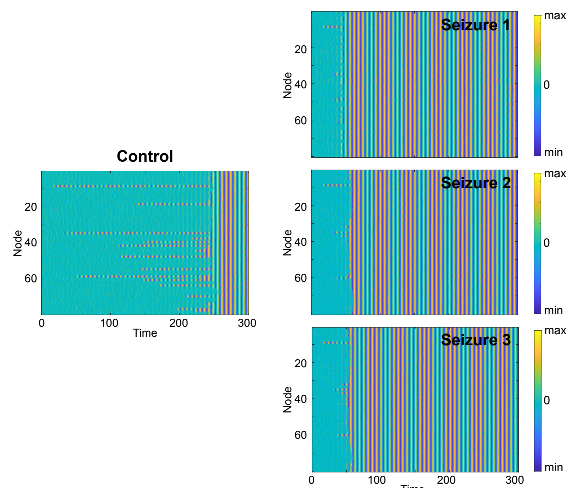
Simulation: Model Dynamics

$$\dot{z_k} = (a|z_k|^4 + b|z_k|^2 + \lambda + i\omega)z_k + \beta \sum_{j=1}^{N} C_{kj} z_k + \eta(t),$$

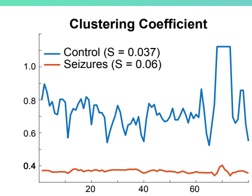
- ω controls the frequency of oscillations
- λ determines attractors of the system
- (a,b) are real constant coefficients
- Each node in a network of N nodes is connected with bidirectional functional connectivity (C)
- η is a complex noise



Simulation: Seizure Dynamics



Network Measures of Simulated Models

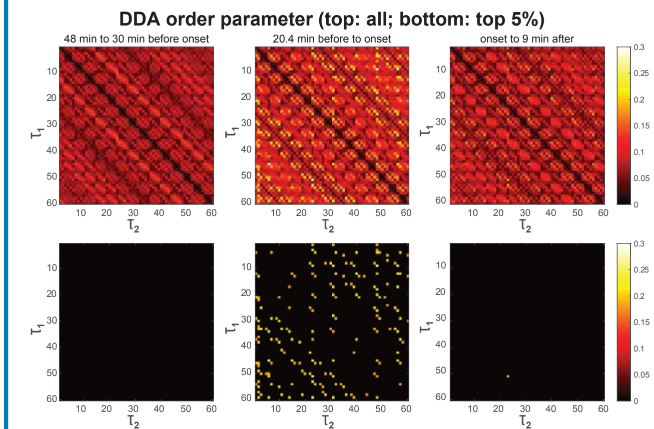


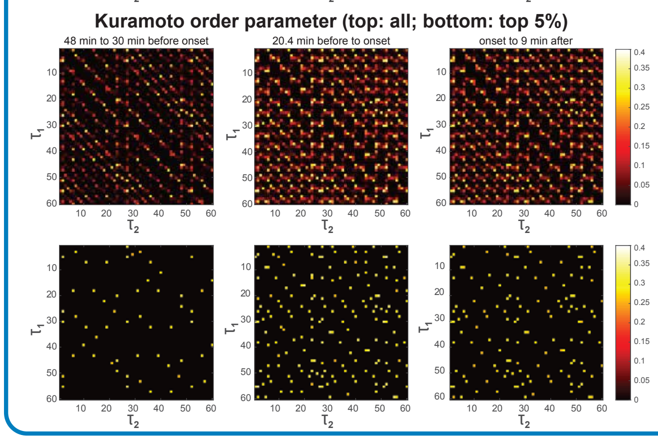
Synchronizability (S)

$$s = \lambda_2^L / \lambda_{Max}^L,$$

- λ_2^L and λ_{Max}^L denote the second smallest and the largest eigenvalue of the Laplacian matrix L $(L = D - A)$
- A is adjacency matrix of the network, and D is its degree matrix

Quantifying Chimera States





Conclusions

- By simulating epileptic models, we showed that seizure activities can be detected through the level of instability in the network.
- In addition, this network instability is accompanied by dynamical chimeras where the brain goes into states of partial synchrony at the onsets of epileptic seizures.

Reference

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