# High-Dimensional Directional Network Analysis for Focal Seizures

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# Introduction

- The brain is a high-dimensional directional network system as it consists of many components, and these components exert influences on each other.
- The directional influence from one region to another is referred to as a directional connection.
- We identify normal and abnormal directional brain networks of patients with epilepsy.

# Existing Network Studies

- Networks with functional connectivity, such as PCA and ICA.

- Low-dimensional directional networks.

# Epilepsy

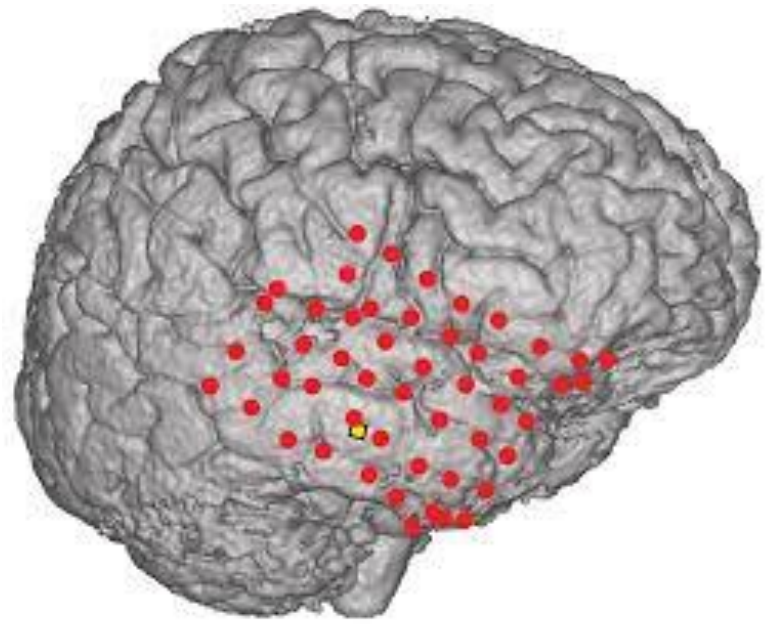
- Epilepsy is the fourth most common neurological disorder, affecting approximately 3 million people in the U.S..
- In the epilepsy setting, when a seizure occurs, the abnormal, excessive neuronal activity starts at the seizure onset zone (SOZ) and spreads quickly to other regions.
- https://www.youtube.com/watch?v=BvqA3vbNYPc

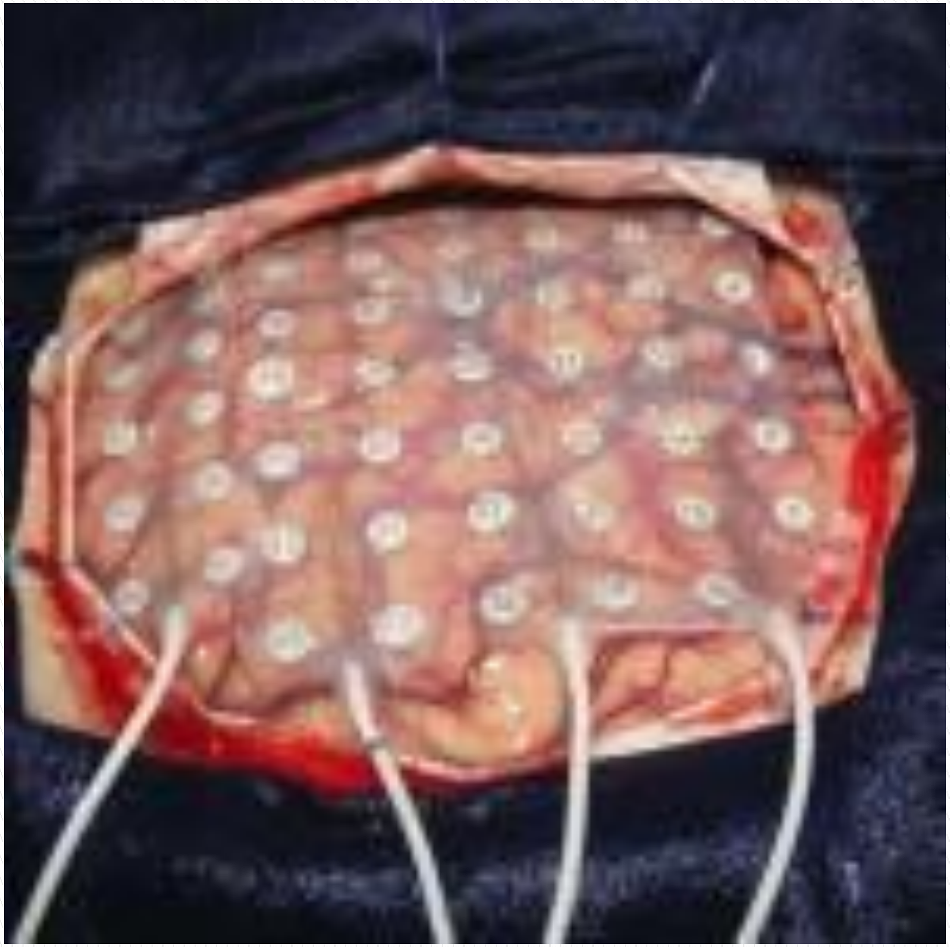
- Epilepsy is a directional network disorder, as seizures propagate from the seizure onset zone to other regions.
- We want to know how seizures change the structure of directional brain networks from normal to abnormal, epileptic states.
- Use high-dimensional multivariate time series recordings of activities in regions to identify connected regions, i.e., to map brain networks.

# iEEG Data

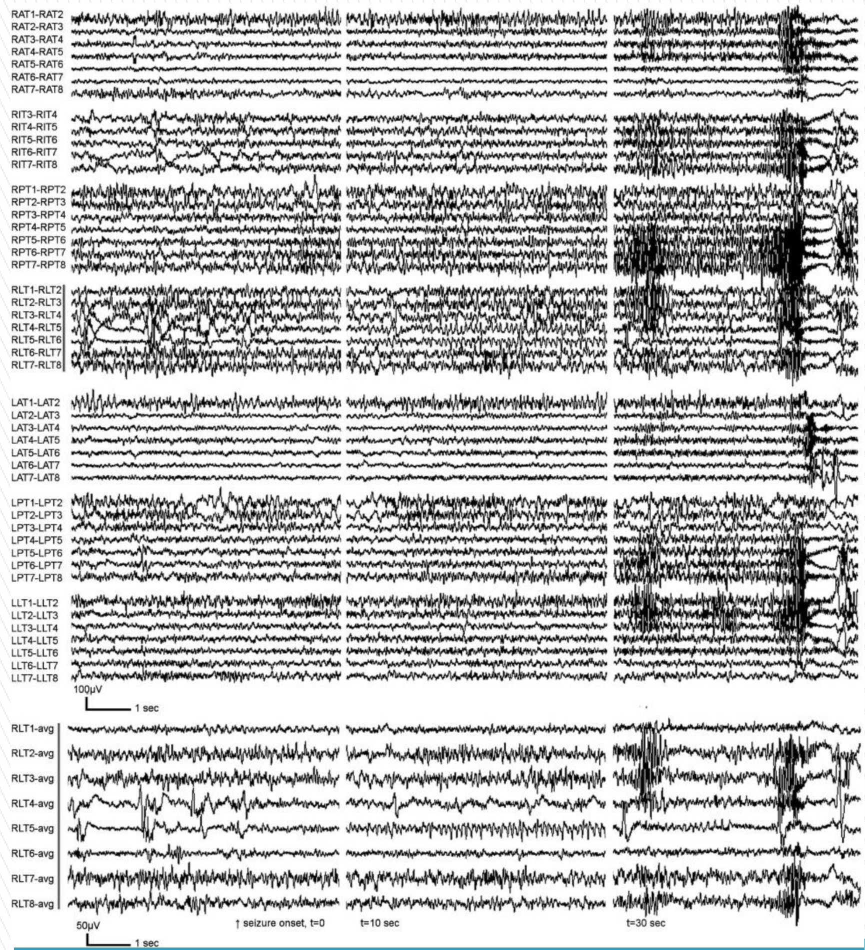
- Intracranial EEG, is a form of electrophysiology whereby electrodes are placed directly inside the skull and dura on a living human cortex.

- iEEG's high temporal resolution and spatial localization make it an ideal data for studying the human brain.





iEEG Electrode Placement




iEEG Recordings

# Advantages of iEEG data

- High temporal resolution.
- High Spatial resolution.
- Strong signal-to-noise ratio.

# Epilepsy Diagnosis

- The best chance for patients with drug resistant epilepsy to achieve seizure control is to surgically resect the seizure onset zone (SOZ).
- Trained EEG experts visually examine iEEG data and identify the SOZ as the brain region that first shows abnormal epileptic activity.
- The neuronal patterns are difficult to characterize by visual inspection alone and the region that first shows visually detectable abnormal activity may not be the SOZ.

# Challenges in Identifying High-Dimensional Directional Networks

- Difficulty in finding an appropriate model.

- Large estimation errors.

- Computational costs.

# Existing Methods

- Information-theoretic measures including directed transinformation and partial directed coherence (Baccal´a and Sameshima, 2001).

- Model-based methods: ordinary differential equation (ODE) models, Dynamic Causal Modeling (Friston 2011).

- High-dimensional linear ODE models (Zhang et al, 2015, 2017, 2019).

# Problems of ODE Models

1. ODE model estimates are sensitive to data noise.
2. ODE model estimation is computationally expensive.
3. The temporal resolution of the observed data can affect the analysis results.

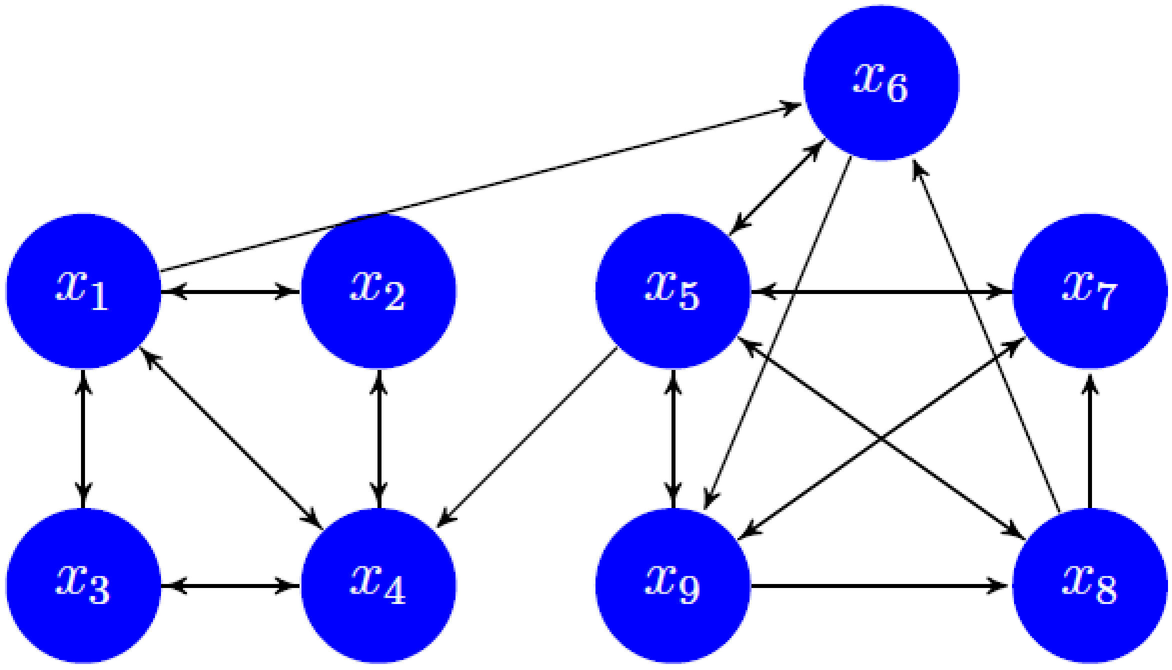
- To address the challenges in identifying high-dimensional directional networks, we integrates a multivariate autoregressive state-space model (MARSS) with a clustering structure to model high-dimensional directional brain networks.

# Brain Network Model

$$y_i(t) = c_i \cdot x_i(t) + \epsilon_i(t), \quad i = 1, \ldots, d$$

$$x_i(t) = \sum_{j=1}^{d} \gamma_{ij} \cdot A_{ij} \cdot x_j(t-1) + \eta_i(t)$$

# The Clustering Structure



# Clustering Structure/Modularity of Brain Networks

- The modularity is widely reported in the literature (Girvan & Newman, 2002; Milo et al., 2002, 2004; Newman, 2003, 2006)

- The modularity of brain's architecture effectively insulates functionally bound subsystems from spreading perturbations due to small fluctuations in structure or dynamics. (Sporns, 2011)

# Stochastic blockmodel (SBM)

- The SBM is a generative model for network patterns in the cluster structure and mostly used for observed network data (Lorrain and White,1971; Holland et al., 1983; Fienberg et al.,1985; Airoldi et al., 2008; Zhao et al., 2011&2012; Wilson et al.,2013).

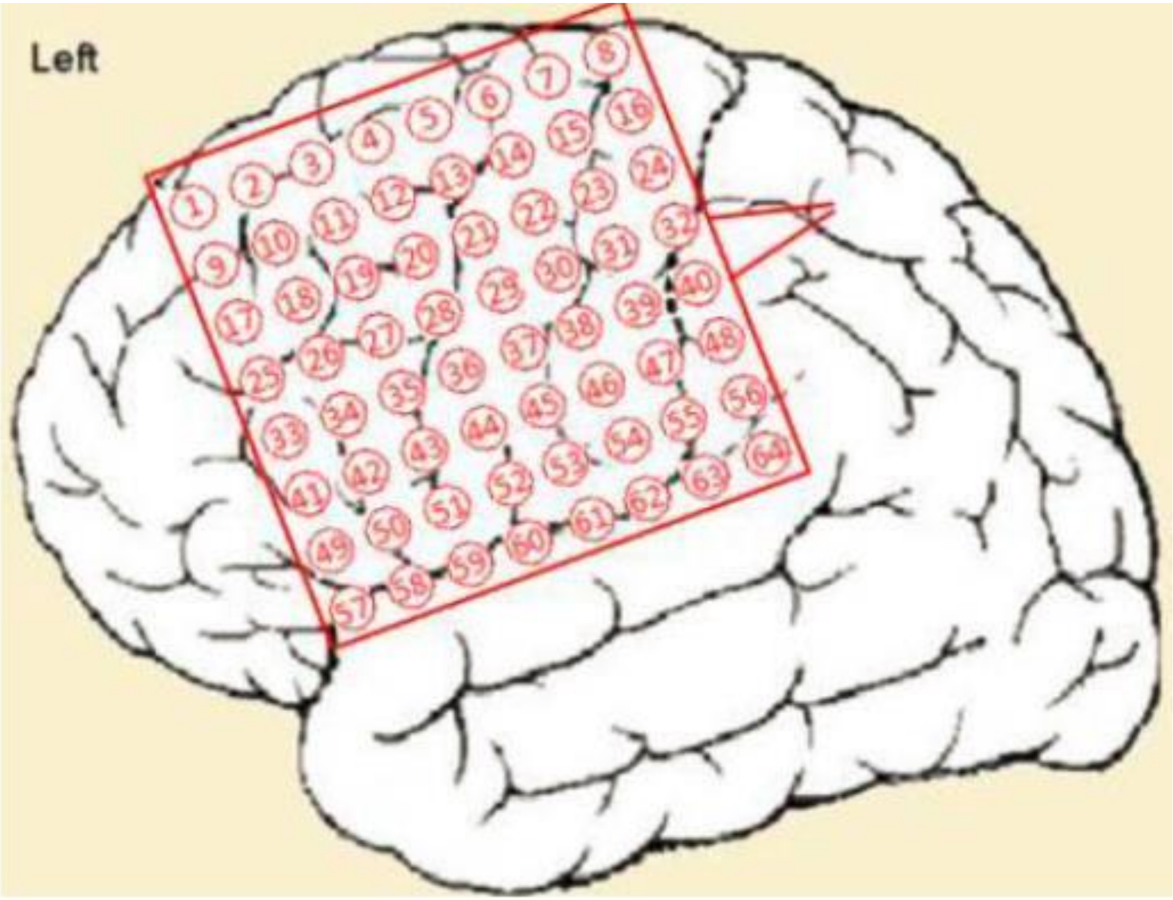
- We propose to make inferences about the underlying network within a Bayesian framework by using a prior motivated by the SBM.

- We develop a Bayesian framework that integrates the clustering structure and the data information to make inferences of regions' directional connections and clusters assignments.

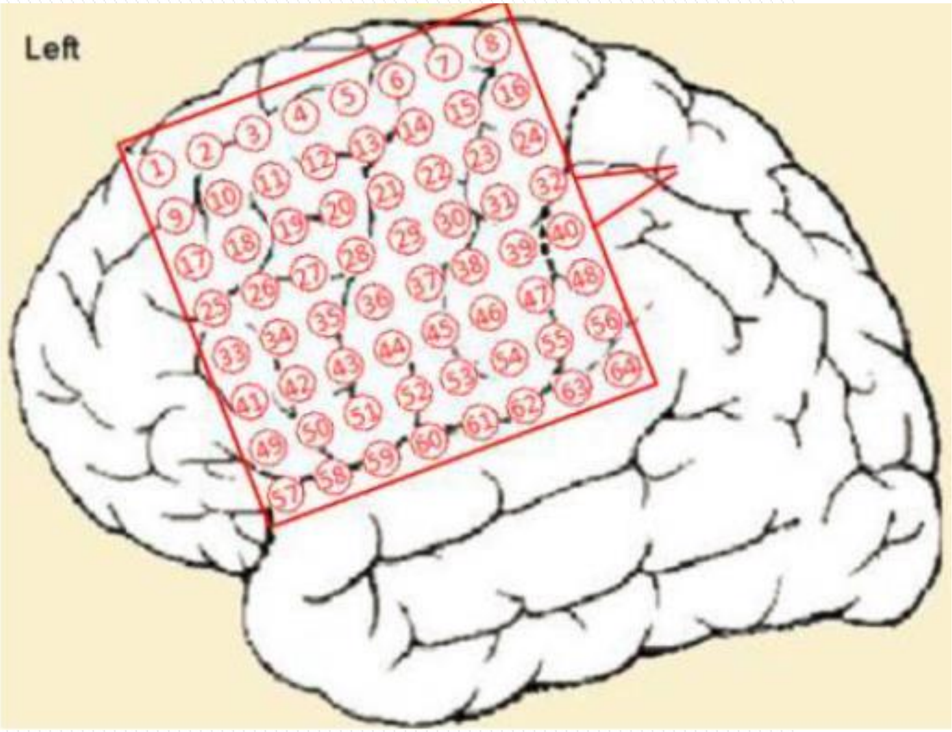
- The identified directional brain network consists of clusters and directional connections among regions.

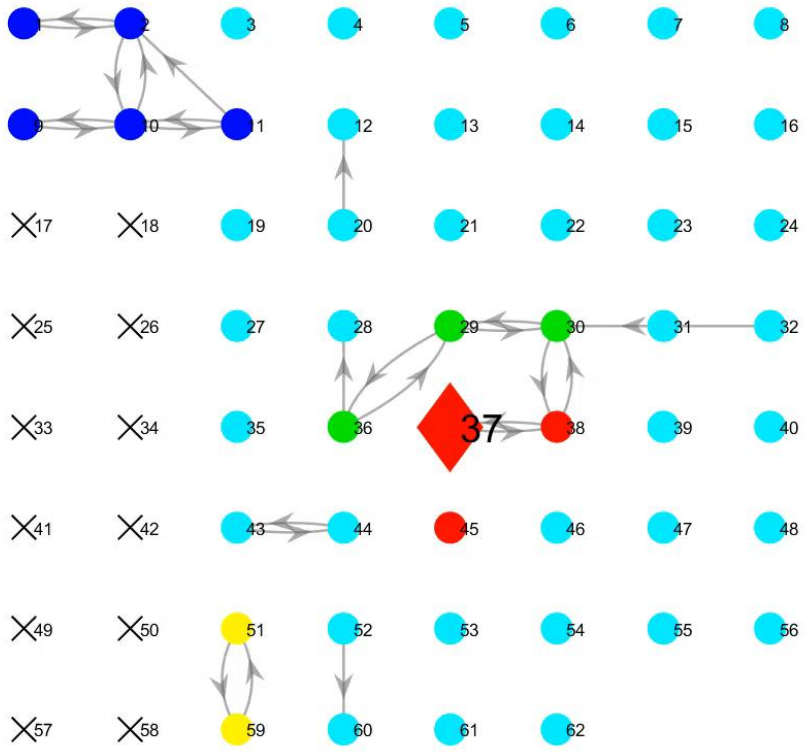
- For the brain network of patients with epilepsy, the SOZ cluster is of special interest.

# Real iEEG Data Analysis




- Region G37 is identified to be seizure onset zones by clinicians.



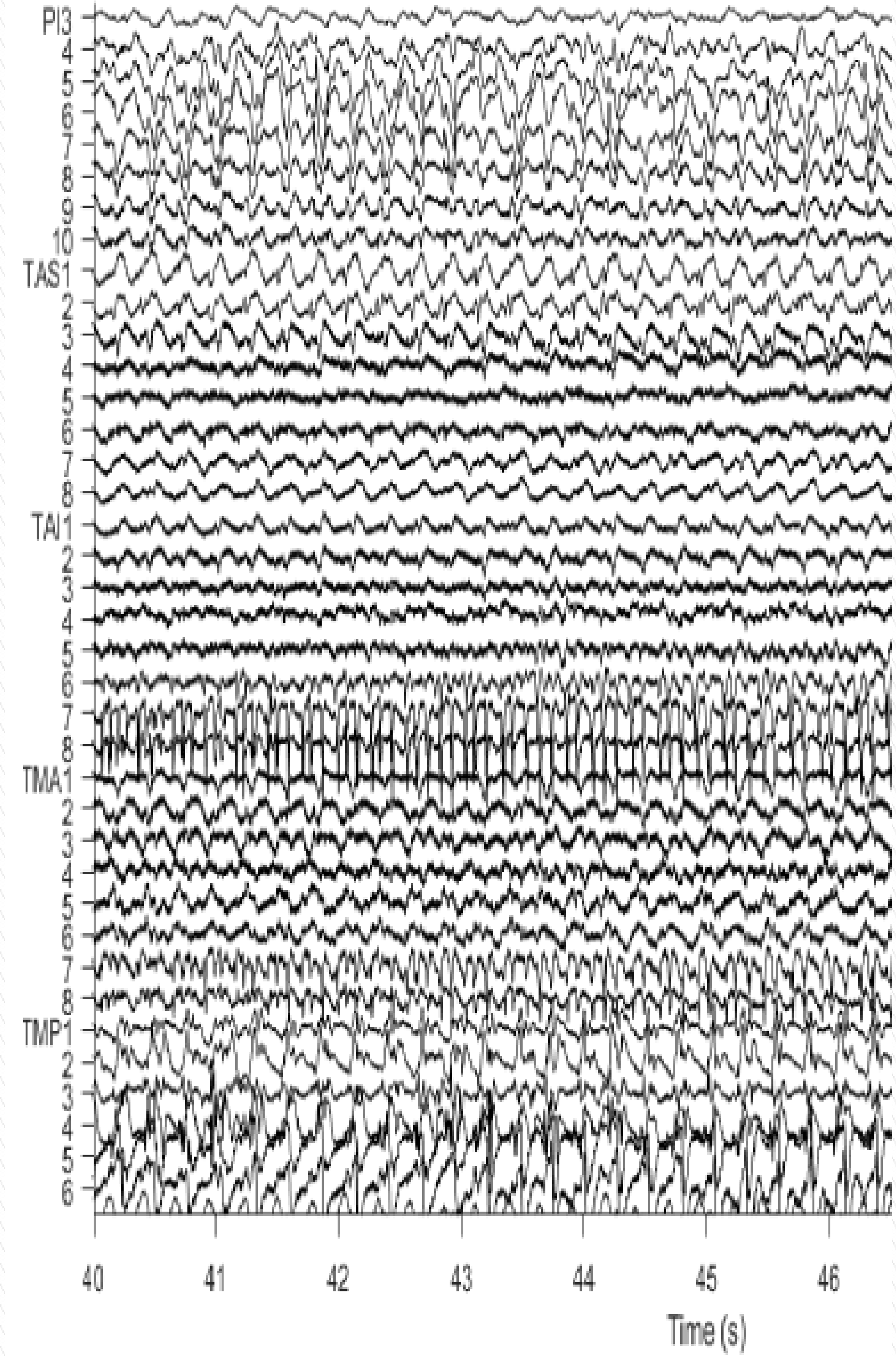



Electrode

300-275B

# Brain Network Changes

- The directional brain network is sparse and stable over time before seizure onset.
- Before seizure onset, the SOZ cluster is small and contains only a few regions, most of which are immediately adjacent to the SOZ.
- After seizure onset, the number of directional connections and the size of the SOZ cluster increase significantly.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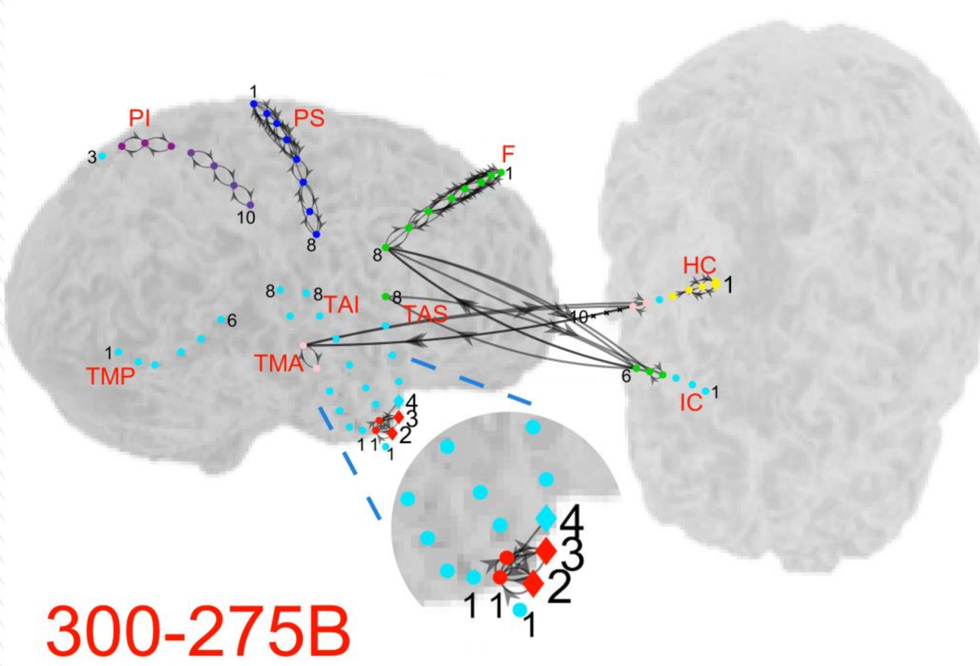
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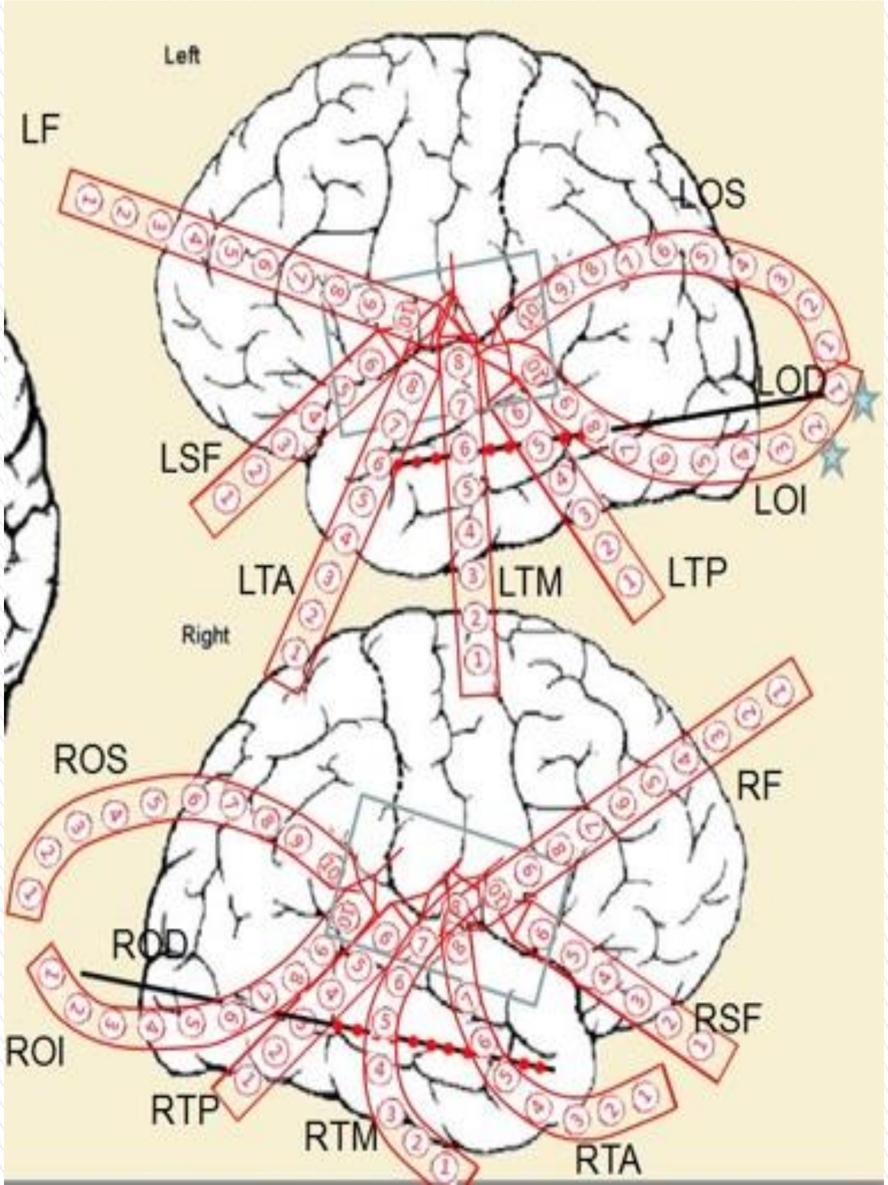
# SOZ Localization




- SOZ by neurologists' visual interpretation of EEG:
- **ROD1-2, RTA1-3, RTM2-4**
- Identified regions by our method:
- RTP1, **RTM4**, RTM5, RTP2, RTM6, **ROD2**, RTM8,**RTA1**

# Summary

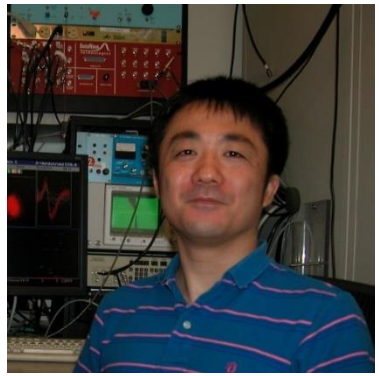
- Propose a new high-dimensional dynamic system model for the brain's direction interactions.
- Using a scientifically motivated prior for brain networks, we develop a new Bayesian framework for inferring the high-dimensional model.
- Use the proposed method to map normal and abnormal epileptic brain networks.

# Impact

- Our method is able to reveal that the epileptic brain networks had dramatic changes at the time of seizure initiation and propagation.
- Our method will be useful for individual diagnosis of epileptic patients with different seizure types and SOZ locations and will lead to substantially more accurate SOZ identification, potentially improving the success rate in epilepsy surgery.
- Our method of SOZ identification has a potential to revolutionize the efficiency of the evaluation phase of epilepsy surgery, thereby reducing the distress of the patients and the cost of health-care providers.

# Acknowledgement


- Mark Quigg and Seiji Tanabe and Guofen Yan.


- My Student Yaotian Wang.

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- ***Thank you!***

- ***Questions?***