Functional Connectivity States of the Brain Using Restricted Boltzmann Machines

Zeynep Kahraman
Boğaziçi University

Selin Aviyente
Michigan State University

Introduction

- **Aim:** Identification of a small number of network states that describe the patterns of brain connectivity during rest.
- **Methodology:** Feature extraction using a restricted Boltzmann machine (RBM) with input as the dynamic functional connectivity networks (dFCN).
- Constructing dFCN relies on sliding window correlation, which helps to understand the time-varying nature of FC.

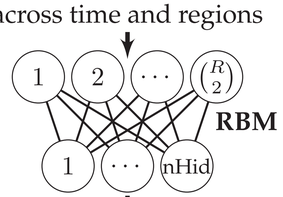
Dynamic FC Networks

Resting-state fMRI
↓
Preprocessing via CONN
↓
Windowing
↓
Correlation matrices of windowed signals by gLASSO
↓
Dynamic Functional Connectivity Networks

Input: Bangor rs-fMRI dataset from the 1000 Functional Connectomes Project containing 20 healthy subjects.

RBM

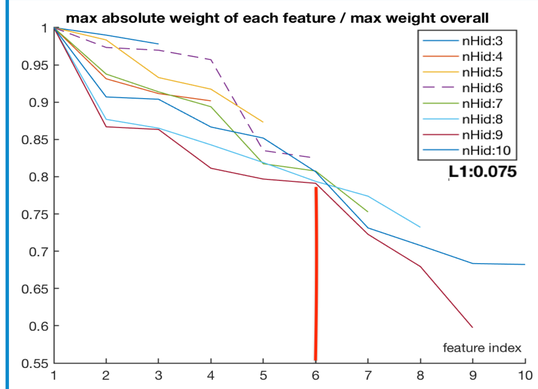
Vectorize dFCN of each window
↓
Construct a matrix of size $W \times \binom{R}{2}$ across time and regions



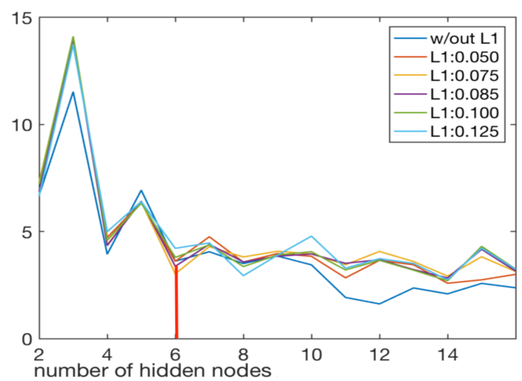
↓
$nHid$ times feature vector of length $\binom{R}{2}$
↓
FC States

W:	number of windows
R:	number of brain regions
$\binom{\mathbf{R}}{\mathbf{2}}$:	number of connections in a network
nHid:	estimated number of FC states & number of hidden nodes of RBM

of hidden nodes in RBM

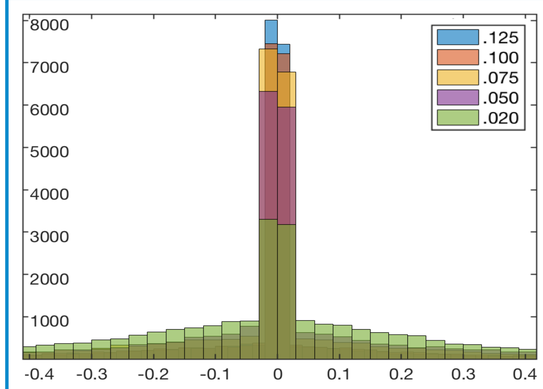


The ratio of the maximum absolute weight for each state to the overall maximum weight is plotted wrt the state (feature) index for RBMs with different $nHid$. Increasing the number of states after 6 will not result in a significant change in data representation.



Occurrence, the ratio of the number of times a particular state occurs to W, is calculated for each state resulting from an RBM with a fixed $nHid$. As the variance decreases, dFCNs are more likely to be uniformly distributed among the resulting states.

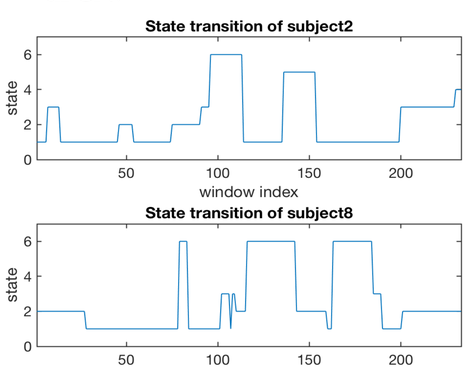
Weight decay rate of RBM

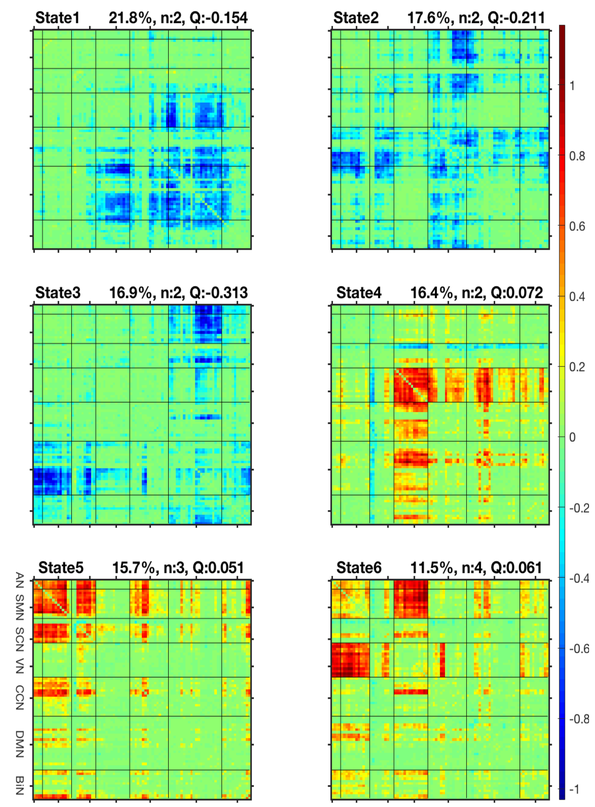


Histogram of the weights of all the states resulting from RBM with $nHid = 6$ and varying weight decay rate (L1-parameter). No significant change in the sparsity of the weights is observed after the weight decay rate 0.075.

FC States

- In State**1** and **3**, DMN is dominant and anti-correlated with sensorimotor regions AN, VN and SMN.
- State**2** is an anti-correlated module consisting of CCN with SMN, AN and SCN.
- State**4** summarizes the interactions of VN with cognitive regions.
- State**5** and **6** illustrate the correlations of sensorimotor regions with each other.
- FC states obtained by RBM are highly modular and representative of the patterns in dFCN.





Future Work

- This research can be extended by considering multiple layers to improve the accuracy of the states.
- Neurological diseases can be diagnosed by comparing the FC states and state transitions of patient and healthy populations.

References

[1] R.D. Hjelmb, V.D. Calhoun, R. Salakhutdinovc, and et al. Restricted Boltzmann machines for neuroimaging: an application in identifying intrinsic networks. *Neuroimage*, 96:245–260, 2014.

[2] E.A. Allen, E. Damaraju, S.M. Plis, E.B. Erhardt, T. Eichele, and V.D. Calhoun. Tracking whole-brain connectivity dynamics in the resting state. *Cerebral Cortex (New York, NY)*, 24:663–676, 2014.

AN: auditory
SMN: somatomotor
SCN: subcortical
VN: visual
CCN: cognitive control
DMN: default mode
BiN: bilateral limbice