Granger Causality Between Functional Brain Networks

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INTRODUCTION

Networks are everywhere, from social to biological sciences. Usually they are represented by graphs, i.e., mathematical objects composed of a set of vertices and a set of edges. However, a vast number of natural networks are dynamic and current methods typically ignore a key component: time.

Supposing that two time series of graphs, $y_{i,t}$ and $y_{j,t}$ are generated by models whose parameters are random variables, we define, inspired by [1], that $y_{i,t}$ does not Granger cause $y_{j,t}$ if the models parameters for $y_{i,t}$ does not Granger

DIFFERENTIAL CONNECTIVITY BETWEEN BRAIN HEMISPHERES IN AUTISTIM

We analyzed rs-fMRI and phenotypic data from 737 subjects for whom the mean framewise displacement (FD) is not greater than 0.2 from the Autism Brain Imaging Data Exchange I (ABIDE I) dataset [3]. For each subject, we performed the pre-processing steps shown in Figure 3.

 $\frac{W_{Right->Left}^{\lambda}-1}{\lambda} = \alpha + \beta_{FD}FD + \beta_{SEX}SEX + \beta_{AGE}AGE + \beta_{ASD}ASD + \beta_{SEX*AGE}SEX * AGE + \beta_{AGE*ASD}AGE * ASD + \gamma_{SITE} + \varepsilon$



cause the model parameters $y_{j,t}$.

Although the models and consequently the parameters of graphs are usually unknown, the spectral radius is a function of the models parameters, capturing intrinsic structural and dynamical characteristics of the graph.



Figure 1: For (A) Erdös-Rényi, (B) geometric, (C) regu-

Table 1: Results considering the Wald's test statistic for assessing Granger causality from the right to the left hemisphere, from gVAR with order p = 5.

Parameter	Estimate	Std. Error	P-value
α	2.5270	0.2163	< 0.0001
eta_{FD}	-0.9295	0.8893	0.2963
β_{SEX}	0.5956	0.2291	0.0095
β_{AGE}	0.0082	0.0073	0.2619
eta_{ASD}	0.2945	0.1731	0.0893
$eta_{AGE*ASD}$	-0.0204	0.0089	0.0220
$\beta_{SEX*AGE}$	-0.0290	0.0126	0.0215

Figure 3: (A) For each subject, we mapped the brain regions according to the AAL atlas and excluded 26 cerebellar regions. (B) We obtained 45 regions on each hemisphere of the brain. (C) To preserve the sampling rate, we estimated a Pearson correlation graph for each hemisphere at each time point. (D) Finally, we applied the gVAR method.



lar, (D) Watts-Strogatz, and (E) Barabási-Albert random graphs, spectral radius is a function of the parameters.

We propose a methodology, called gVAR, that identifies Granger causality between time series of graphs by fitting a vector autoregressive (VAR) model on the time series of the spectral radii (the largest eigenvalue of the adjacency matrix of the graph).

Considering that $y_{i,t}$ is the spectral radius of the *i*th graph at time t, the gVAR(p) model is:

 $y_{i,t} = \alpha_i + \sum_{j=1}^{K} \sum_{l=1}^{p} \left(\beta_{j,i}^l y_{i,t-l}\right) + u_{i,t}, \text{ for } i = 1, \dots, K$

Figure 4: Significant interaction effect between AGE and diagnostic of ASD for the Granger causality from the right to the left brain hemisphere considering (A) male subjects and (B) female subjects.

Figure 5: Differential Granger causality from the right to the left hemisphere in autistic subjects considering only females aged 6 to 13 years (p-value = 0.0147) and considering only males aged 16 to 60 years (p-value = 0.0096).



BRAIN-BRAIN INTERACTION OF TWO PROFESSIONAL VIOLINISTS

We analyzed 23-channel functional Near Infrared Spectroscopy (fNIRS) signals simultaneously acquired from both violinists while they were playing an 30s excerpt of Antonio Vivaldi's Allegro from the Concerto No 1 in E Major, Op. 8, RV 269, "Spring" [2]. The participants are 50 and 41 years old, males, right-handed, and have 40 and 28 years of regular practice. The sampling rate for the experiment was 7.81 Hz.

GVAR R PACKAGE

The R package implementing the gVAR method is available upon request to the authors.

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Spectral–Radius Signals for Both Violinists

Cross Correlation Function (CCF) Between the Spectral-Radius Signals for Both Violinists



Figure 2: By VAR modeling the time series of ranked spectral radii (left plot) using order 10 (delay of 1.28 seconds, selected via AIC), we identified Granger causality from the first violinist (older and more experienced) to the second violinist (p-value = 0.0487). The same results were obtained by using orders 7 to 12 (delays of 0.89 to 1.53 seconds).

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