# Measuring Asymmetric Connectivity in the Default Mode Network

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**Introduction:**

Directed graph representations of brain networks are increasingly being used in brain image analysis to indicate the direction and level of influence among brain regions. Most of the existing techniques for directed graph representations are based on time series analysis and the concept of causality, and use time lag information in the brain signals. Studies have shown that these time lag-based techniques can be inadequate for functional magnetic resonance imaging (fMRI) signal analysis due to the limited time resolution of fMRI as well as the low frequency hemodynamic response [4]. The aim of this work is to present a novel measure of necessity that uses asymmetry in the joint distribution of brain activations to infer the direction and level of interaction among brain regions. We derived a mathematical formula for computing necessity and extended this measure to partial necessity, which can potentially distinguish between direct and indirect interactions. These measures do not depend on time lag for directed modeling of brain interactions and therefore are more suitable for fMRI signal analysis. We performed ROI-wise analysis using the proposed necessity measures to study the default mode network.

**Methods:**

We derived a new measure of directed connectivity based on a notion of necessity. Since this measure does not distinguish between direct and indirect interactions, we extended necessity to a partial necessity measure. These measures indicate the presence of asymmetry in the joint distribution of fMRI signals from two different ROIs (see Fig. 1). We used the Kernel Density Estimation Toolbox for MATLAB for the purpose of multivariate joint and conditional probability density estimation [2]. We applied the necessity and partial necessity measures to resting state fMRI data. The dataset used for this work was provided by the Human Connectome Project (HCP). This data was processed using the HCP preprocessing pipeline, which involves the use of a denoising process referred to as ICA-FIX [5]. For the analysis presented in this work, we focused on the default mode network, in particular the following ROIs: Posterior Cingulate - Dorsal, Posterior Cingulate - Ventral, Inferior Parietal - Angular, Inferior Parietal - Supramarginal, and Superior Frontal. ROI-wise time series were computed by averaging the fMRI signal over each ROI. The fMRI time series for each ROI was normalized by subtracting the mean, taking the absolute value, and then dividing by the standard deviation of the signals from all ROIs. By using the error function, the resulting signal was constrained to the [0,1] interval. For a given pair of ROIs, we compared the necessity values in both directions using a one-sided rank-sum test, and reported the difference when there is significance.

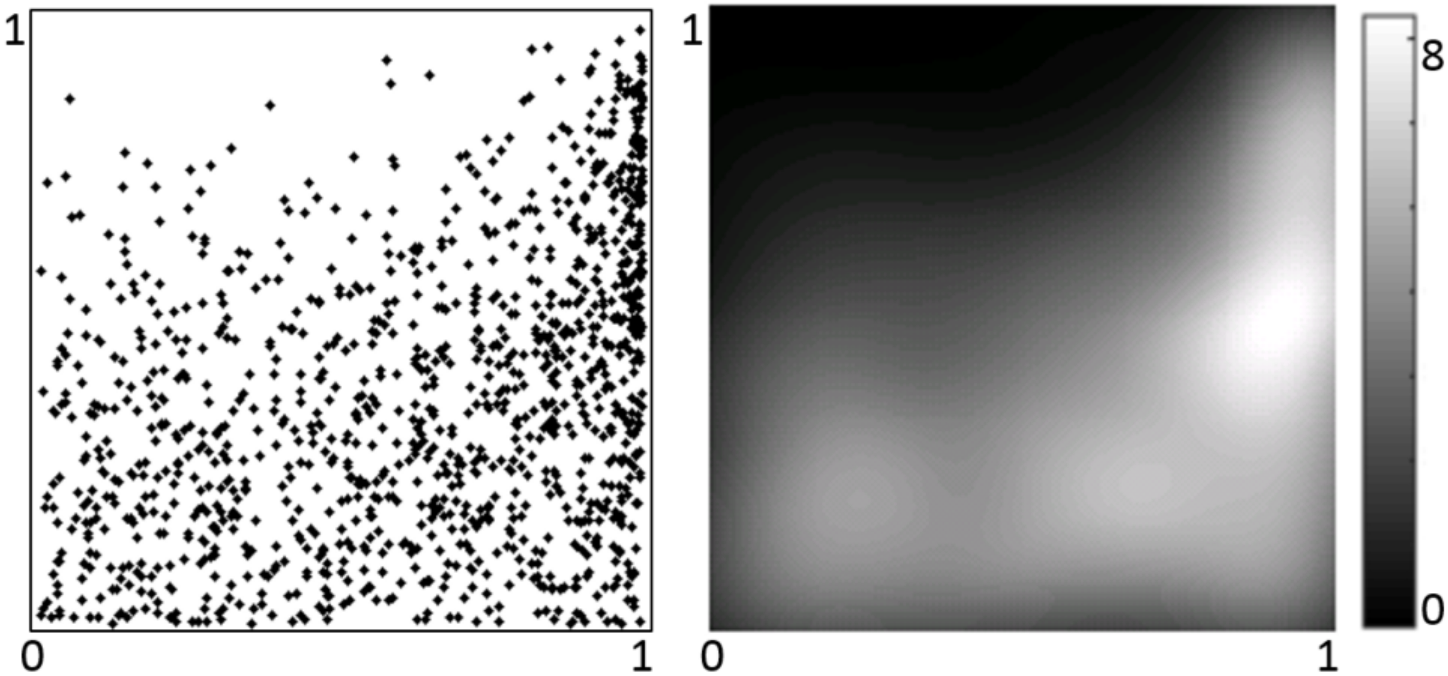


**Fig. 1.** (a) A scatter plot of activation of left posterior cingulate gyrus – dorsal (x-axis) and left inferior parietal lobule – angular gyrus (y-axis) from a resting-state fMRI data set; (b) Kernel density estimate of the joint distribution. The lower-triangular shape of the joint distribution is consistent with a directed necessity relationship from the former ROI to the latter.

**Results:**

We used the proposed necessity measures to study connectivity and directed interactions in the default mode network. Studies have shown that the posterior cingulate cortex (PCG) forms a central node in the default mode network [1,3]. In this analysis, we compared our proposed necessity measures to the popularly used partial correlation measure (see Fig. 2). In the case of the necessity measures, we can see that the majority of the arrows are originating from the PCG. This indicates that activation of the PCG is necessary for activation of the other ROIs in the network, thus supporting the notion that the PCG is a central hub in the default mode network. However, this is not evident from the undirected partial correlation measure.

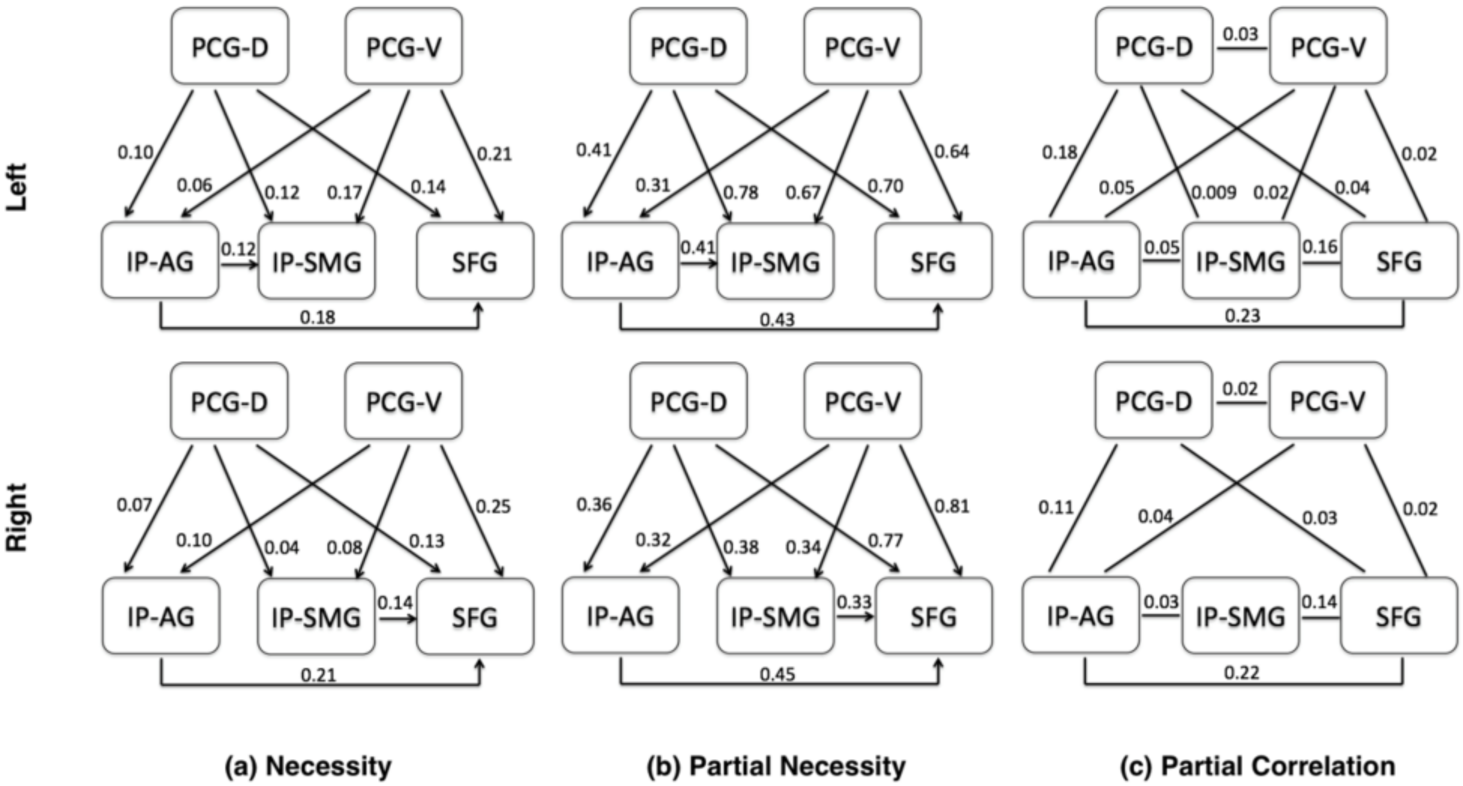


**Fig. 2.** Study of connectivity and directed interactions in the default mode network. We studied connectivity in the default mode network using three measures: (a) Necessity, (b) Partial Necessity, and (c) Partial Correlation. The ROIs we studied are as follows: PCG-D = Posterior Cingulate Gyrus - Dorsal; PCG-V = Posterior Cingulate Gyrus - Ventral; IP-AG = Inferior Parietal Lobule - Angular Gyrus; IP-SMG = Inferior Parietal Lobule - Supramarginal Gyrus; SFG = Superior Frontal Gyrus. The top and bottom rows illustrate connectivity in the left and right hemispheres, respectively.

**Conclusions:**

We presented a measure of necessity and partial necessity for exploring asymmetric brain interactions during resting state. These measures are particularly useful in the context of fMRI data analysis because they do not depend on time lag information. Preliminary results indicate that activation of the posterior cingulate gyrus is necessary for activation of other ROIs in the network thus supporting the notion that this region acts as a central hub.

**Imaging Methods:**

BOLD fMRI

**Modeling and Analysis Methods:**

fMRI Connectivity and Network Modeling [1]

Multivariate modeling [2]

Task-Independent and Resting-State Analysis

**Poster Session:**

Poster Session - Thursday

**Keywords:**

Data analysis

FUNCTIONAL MRI

*[1|2]Indicates the priority used for review*

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Yes

**Please indicate below if your study was a "resting state" or "task-activation” study.**

Resting state

**Healthy subjects only or patients (note that patient studies may also involve healthy subjects):**

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Not applicable

**Please indicate which methods were used in your research:**

Functional MRI

Computational modeling

**For human MRI, what field strength scanner do you use?**

3.0T

**Which processing packages did you use for your study?**

Other, Please list - HCP

**Provide references in author date format**


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