Neuroengineering 2020-2021

September 17th, 2021 – Part II

A.Y. 2020/21

Carefully read the following scenario and answer the questions listed below.

A study is conducted with the aim to **understand the brain organization** in a **neurological pathological condition** mostly affecting **elderly patients**.

The subjects enrolled in the study undergo an **EEG screening** during the **resting state**. They are seated in a comfortable position in a quiet, dim room and they are just asked to relax for the duration of the recordings.

Six cortical regions (3 for each hemisphere, 2 in the frontal lobe and 1 in the parietal lobe) are selected for a connectivity study of **causality in the statistical sense**. The goal is to describe the network properties in terms of **integration** and **segregation** between different modules.

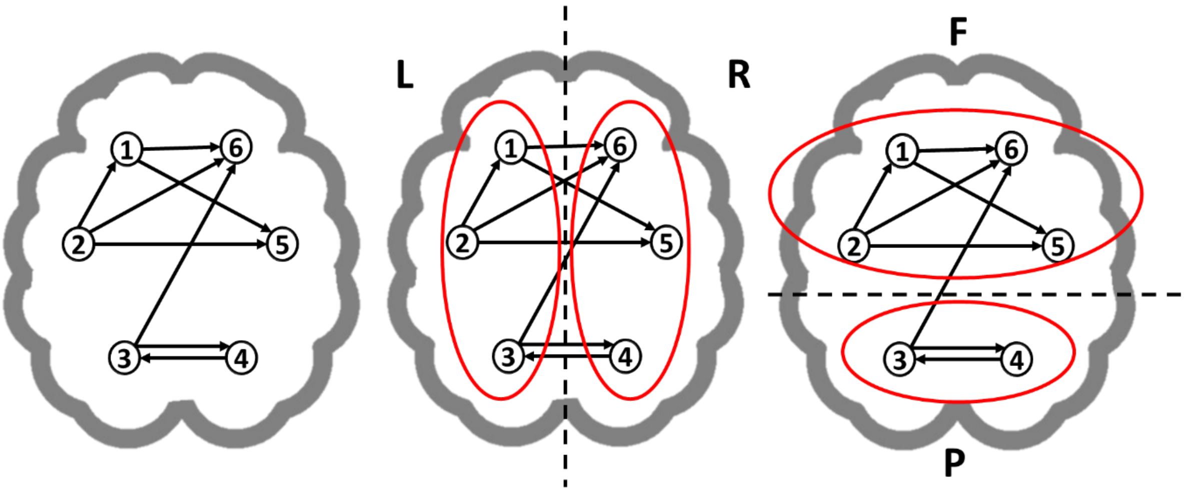


Fig. 1-A Fig. 1-B Fig. 1-C

Questions

Q1 – Indicate **which connectivity estimator** you would use to perform the **network analysis**. **<u>Motivate your choice</u>**. *NB: the answer and the motivation are independent from the networks depicted in Fig.1.* *(3 points)*

(write the answers in the exam.net editor)

Q2 – Assuming that the network analysis returns the functional network reported in **Fig. 1-A:** **Q2.1:** Extract the corresponding **adjacency matrix** *(1 point)* **Q2.2:** Compute the **Indegree** and the **Outdegree** for each node *(1 point)* **Q2.3:** Compute the **Divisibility D** and the **Modularity Q** of the network, considering the two hemispheres as classes, like in **Fig. 1-B**: C=[1,1,1,2,2,2] *(2 points)* **Q2.4:** Compute the **Divisibility D** and the **Modularity Q** of the network, considering the frontal lobe and the parietal lobe as classes, like in **Fig. 1-C:** C=[1,1,2,2,1,1] *(2 points)* *(write the answers on paper)*
Q3 – Given the results obtained at Q2, indicate which of the two divisions in classes (left-right or fronto-parietal) corresponds to a more segregated (=divided in two modules) network. **Motivate your answer**. *(2 points)* *(write the answers in the exam.net editor)*

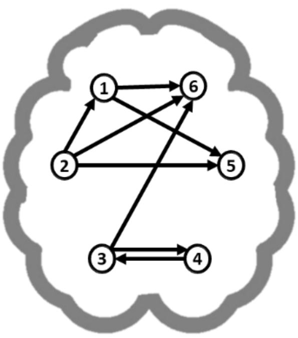
Solutions

Q1: Since the study requires to compute **causality in the statistical sense**, the choice is between the **Granger Test (GT)** and **PDC**.

Since we are dealing with EEG data, we can assume that the **spectral information** is of relevance, so we can select the PDC (which is also more accurate as it mitigates the problem of the hidden source).

Alternate reasoning: since we are not sure that we have enough data to compute PDC (which is multivariate and therefore **not robust to data paucity**) we can also decide to use GT, to stay on the safe side at the expenses of the limitations typical of bivariate approaches.

Q2.1: Adjacency matrix:



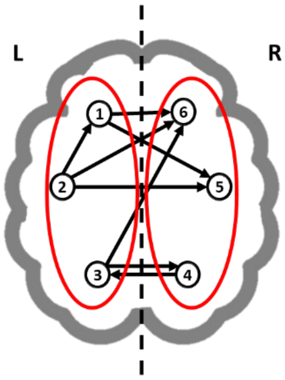
0	0	0	0	1	1
1	0	0	0	1	1
0	0	0	1	0	1
0	0	1	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0

Q2.2: In- and out-degrees:

A=

g_{OUT} \ g_{IN}	1	0	1	1	2	3
2	0	0	0	0	1	1
3	1	0	0	0	1	1
2	0	0	0	1	0	1
1	0	0	1	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

Q2.3:



A=

	g_{IN}	1	0	1	1	2	3	
g_{OUT}	2	0	0	0	0	1	1	1
	3	1	0	0	0	1	1	1
	2	0	0	0	1	0	1	1
	1	0	0	1	0	0	0	2
	0	0	0	0	0	0	0	2
	0	0	0	0	0	0	0	2
		1	1	1	2	2	2	

$N = 6$

$L = 8$

C=[1 1 1 2 2 2]

$$D = \frac{L}{L + \sum_{i,j=1}^{N} a_{ij}\left[1 - \delta(C_i, C_j)\right]}$$

$$D = \frac{8}{8+7} = \mathbf{0.53} \qquad D \in [0.5, 1]$$

$$Q = \frac{1}{L}\sum_{i,j=1}^{N}\left(a_{ij} - \frac{g_i^{OUT} g_j^{IN}}{L}\right)\delta(C_i, C_j)$$

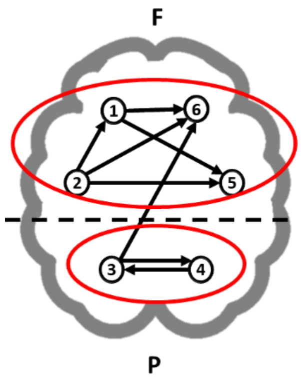
$$Q = \frac{1}{8}\left[1 - \frac{(g_1^{OUT}+g_2^{OUT}+g_3^{OUT})(g_1^{IN}+g_2^{IN}+g_3^{IN})}{8} + 0 - \frac{(g_4^{OUT}g_5^{OUT}+g_6^{OUT})(g_4^{IN}g_5^{IN}+g_6^{IN})}{8}\right] =$$

$$= \frac{1}{8}\left[1 - \frac{(2+3+2)(1+0+1)}{8} + 0 - \frac{(1+0+0)(1+2+3)}{8}\right] = \frac{1}{8}\left[1 - 1.75 + 0 - 0.75\right] = \mathbf{-0.19}$$

Existence of intra-community links

Probability of random links between the nodes

Q2.4:



A=

	g_{IN}	1	0	1	1	2	3	
g_{OUT}	2	0	0	0	0	1	1	1
	3	1	0	0	0	1	1	1
	2	0	0	0	1	0	1	2
	1	0	0	1	0	0	0	2
	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	0	1
		1	1	2	2	1	1	

$N = 6$

$L = 8$

C=[1 1 2 2 1 1]

$$D = \frac{L}{L + \sum_{i,j=1}^{N} a_{ij}\left[1 - \delta(C_i, C_j)\right]}$$

$$D = \frac{8}{8+1} = \mathbf{0.89} \qquad D \in [0.5, 1]$$

$$Q = \frac{1}{L}\sum_{i,j=1I}^{N}\left(a_{ij} - \frac{g_i^{OUT} g_j^{IN}}{L}\right)\delta(C_i, C_j)$$

$$Q = \frac{1}{8}\left[5 - \frac{(g_1^{OUT}+g_2^{OUT}+g_5^{OUT}+g_6^{OUT})(g_1^{IN}+g_2^{IN}+g_5^{IN}+g_6^{IN})}{8} + 2 - \frac{(g_3^{OUT}g_4^{OUT})(g_3^{IN}g_4^{IN})}{8}\right] =$$

$$= \frac{1}{8}\left[5 - \frac{(2+3+0+0)(1+0+2+3)}{8} + 2 - \frac{(2+1)(1+1)}{8}\right] = \frac{1}{8}\left[5 - 3.75 + 2 - 0.75\right] = \mathbf{0.31}$$

Existence of intra-community links

Probability of random links between the nodes

Q3: Given the results obtained, the fronto-parietal division in classes corresponds to a more segregated and less integrated network. In fact, both divisibility and modularity are higher than in the left-right division. In particular, L-R shows a divisibility close to its minimum value (=0.5) and a negative modularity, indicating that the two classes don't act as modules, while F-P shows a divisibility close to its maximum (=1) and a positive modularity, indicating that the two classes are more internally organized than an average group of nodes randomly chosen in the network.

	Divisibility	**Modularity**	
Left-Right	0.53	-0.19	Lower segregation/higher integration
Fronto-Parietal	0.89	0.31	Higher segregation/lower integration