Neurocomputing
709.014 22S
Homework assignment 2

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Previous assignment

In the last assignment, I implemented from scratch a MVAR model, fitting it on a 9 channels acquisition of 5 seconds with sampling frequency of 128 Hz. The model tried to predict the value of all channels at a time point N, based on a linear combination of the p previous samples of that channel and all the others. Changing the value of p will influence the prediction of the model. As a result, I selected the value of p (that is called model order) that leads to the best prediction by applying two different techniques of model selection: one based on a two-fold cross validation, and one based on statistical criteria like AIC and BIC. After the evualtion of the results of both techniques, I selected as best model order p = 3. So, I fitted a MVAR of order 3 to the whole dataset, to better catch the lowest frequencies present in the time-series, and to exploit the possible information coming from all the time points.

Connectivity measurements

The aim of the seminar is to perform effective connectivity on the EEG signal, therefore try to understand which signals are piloting the others and so which are the flows of information. As a results, I need some metrics that are able to evaluate causality of the different connections. Moreover, I would like to perform the analysis in the frequency domain, since usually you can retrieve useful information in this domain, for example regarding brain rhythms. Such metrics are based on the Fourier transform of the coefficients of a MVAR model, that is a model able to give you causality information in the time domain (for example the Granger causality). That's why I fitted a MVAR model to the data in the previous assignment. To calculate these connectivity measurements, I used a pre-build function that calculate the following metrics:

- Coherence (COH). Correlation of time series in the frequency domain (no info regarding causality).
- Partial Coherence ($PCOH$). Correlation of time series in the frequency domain (no info regarding causality) that are only directly connected. So it doesn't take into consideration indirect connections.
- Directed Transfer Function ($DTF_{i \Rightarrow j}$). Percentage of the power of the signal j caused by the signal i. It takes into consideration both direct and indirect connections.
- Partial Directed Coherence ($PDC_{i \Rightarrow j}$). Percentage of the power of the signal j caused by the signal i. It takes into consideration only direct connections.
- Directed Coherence ($DC_{i \Rightarrow j}$). Equivalent of DTF but also taking into consideration the covariance matrix of the residuals of the MVAR model. Useful when you are dealing with

different types of signals at the same time (like EEG and EMG) and you want to normalize the connectivity measurement.

- Generalized Partial Directed Coherence ($GPDC_{i\Rightarrow j}$). Equivalent of PDC but also taking into consideration the covariance matrix of the residuals of the MVAR model. Useful when you are dealing with different types of signals at the same time.

As you can see, the first two measurements will not give directionality information, however they are still important to better understand what it is going on in the brain. In Figure.1, the difference between direct an indirect connection is displayed.

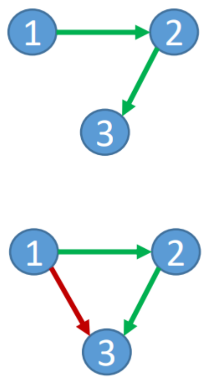

Figure 1: Different connection type. In the top panel only direct connections are visualized. Since node 1 is influencing node 2 that itself influences node 3, also node 3 is indirectly influenced by node 1. The indirect connection is displayed in red in the bottom pannel.

Average connectivity metrics

The Fourier transform gives the opportunity to select the resolution in the frequency domain, usually frequency bins of 1 or 2 Hz are used. As a results, averaged connectivity metrics are calculated for the standard frequency band: delta (D: [0.5 3] Hz), theta (T: [4 8] Hz), alpha (A:[8.5 12] Hz), beta (B: [12.5 30] Hz) and gamma (G: [30.5 60]Hz). In Figure.2 - Figure.7, you can see the different connectivity measurements for each couple of channels in each frequency band. Driver channels are on columns and target channels are on rows. Colours express the magnitude. The diagonal values are set to "not a number" since we are interested only on connections between different signals. Coherence matrices tells that the frontal electrodes are correlated between each others, and the same occurs in the parietal zone (Figure.2). Central zone is correlated with both frontal and parietal areas. However, here we are also considering indirect connections, in fact partial coherence matrices underline that direct connections are less (Figure.3). From Figure.4, it can be seen that channels of the central area (channels C, CL and CR) are the main drivers for almost all the other; in particular in delta band. Same consideration can be retrieved from Figure 5. As expected, even taking into consideration the covariance of the MVAR residual matrix doesn't change the above consideration since the model have similar prediction performances for all the time series (thus, similar variance of the residual). The task performed during the EEG acquisition was a motor imagery task. That's why we see a flow of information exits from the central zone where the primary motor cortex is localized. Moreover, we have seen a peak in the DC and DTF in the delta band since the MI task produces movement related cortical potentials (MRCPs) which are slow rhythms. PDC and GPDC underlines on more time that it is the central area to mainly drives the others, and also it is the zone data is less affected by the others. It can also be appreciated that the information exciting from channels P and PL reaches primary the frontal area (channel F,FL,FR) in particular in delta, theta and alpha band.

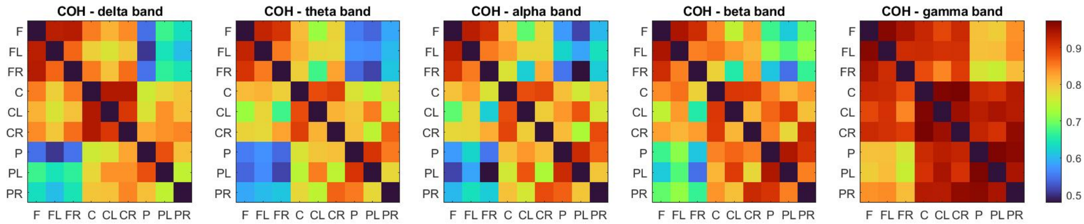

Figure 2: Coherence of the signals in different frequency bands.

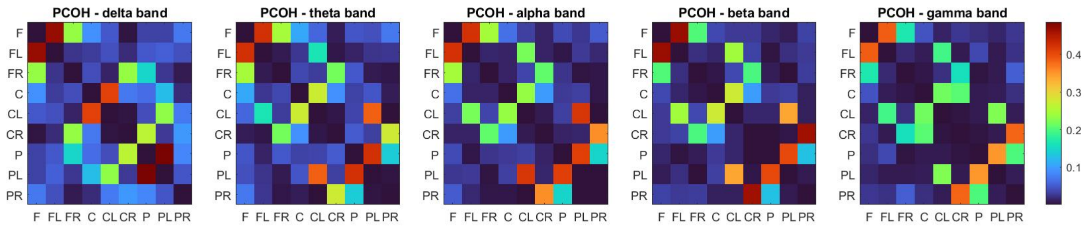

Figure 3: Partial Coherence of the signals in different frequency bands.

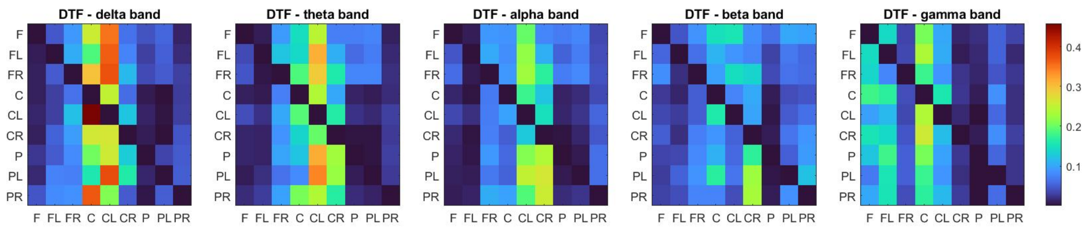

Figure 4: Directed Transfer Function of the signals in different frequency bands.

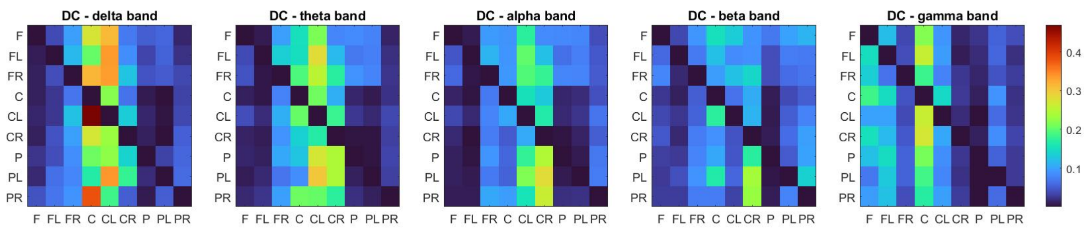

Figure 5: Directed Coherence of the signals in different frequency bands.

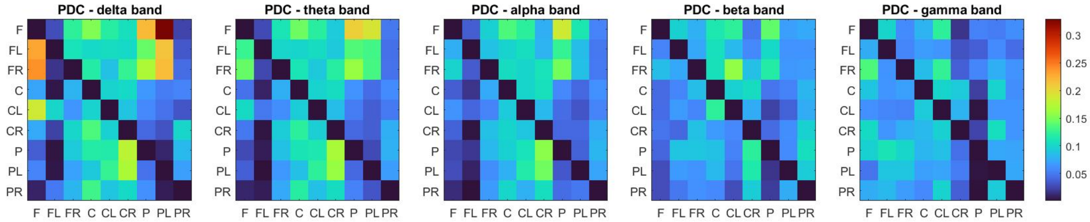

Figure 6: Partial Directed Coherence of the signals in different frequency bands.

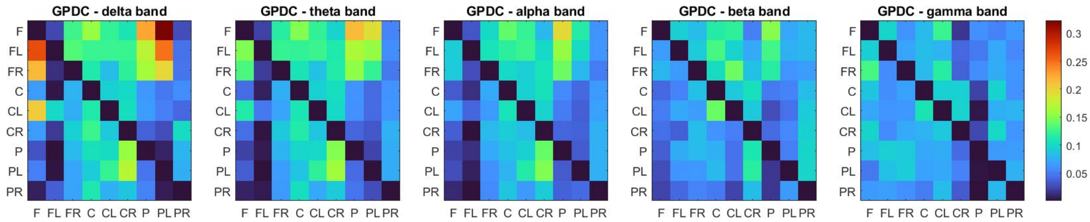

Figure 7: Generalized Partial Directed Coherence of the signals in different frequency bands.

Total information Inflow and Outflow

Calculating the total information inflow/outflow for each channel in each band is a nice way to summarize the previous matrices. It is important to remember that, by construction, the inflow of a channel is normalized to one in DC and DTF. On the other hand, the total information outflow is normalized to one in PDC and GPDC. As a results, to calculate the total outflow I based on DC and DTF by summing all the values on the same column; for the inflow to PDC and GPDC by summing all the values in the same row. In Figure.8 and Figure.9 the information outflow can be seen. Both figures confirm that channels C, CL and CR are the main sources. In particular in theta band channel C and CL have the main outflow, this means that they are piloting other channels in that specific rhythm. From Figure.10 and Figure.11 you can see that the main sinks are channels of the frontal area, in particular in delta band. The analysis of the fluxes of information confirms what stated before. On more time DTF/DC and PDC/GPDC give similar results since the variances of the residual of the model are similar in each time-series.
To sum up, the bar plot representation of the flow of information is useful if you want to quickly understand which are the main sources and sinks, however to appreciate the specific connections between each couple of signals, the measurement matrices are needed. As a results, the bar plots give the main picture, the connectivity matrices supply all the specific details.

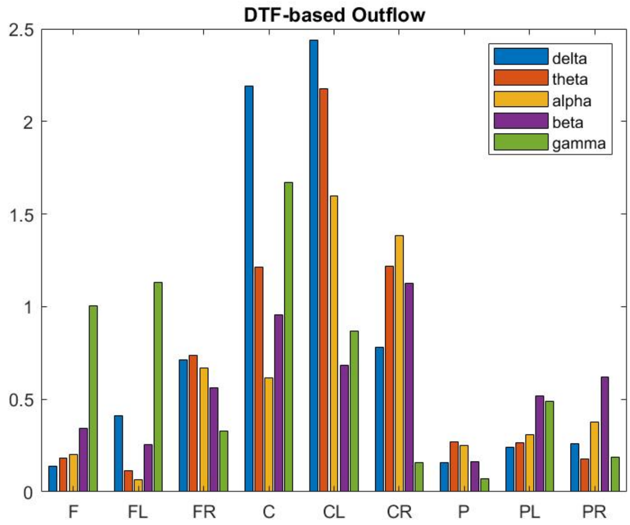

Figure 8: Total information outflow based on the DTF for each diffent channels per frequency band.

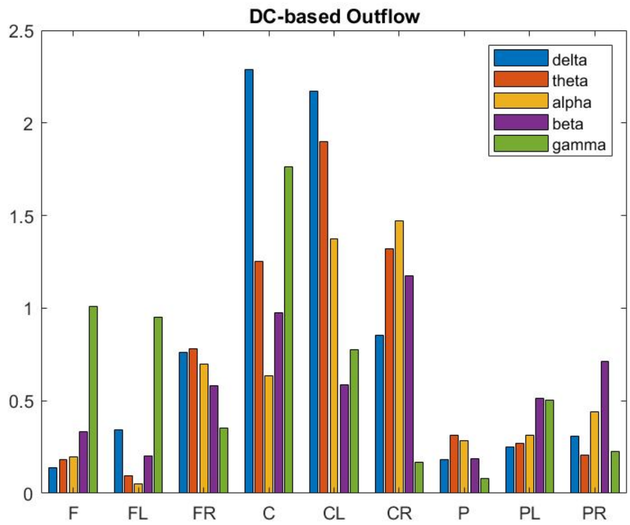

Figure 9: Total information outflow based on the DC for each diffent channels per frequency band.

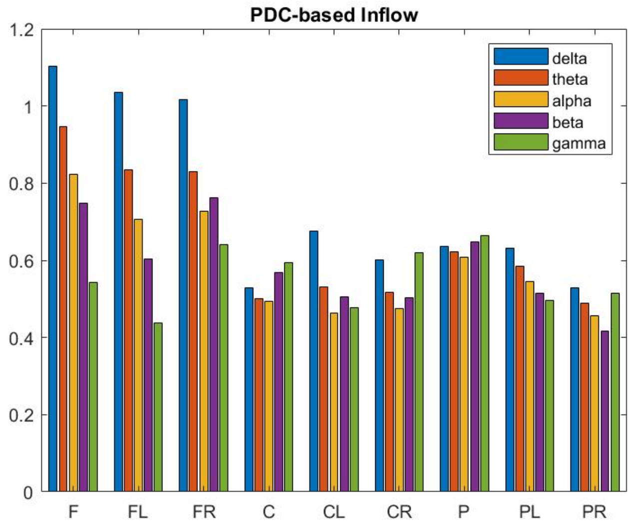

Figure 10: Total information inflow based on the PDC for each diffent channels per frequency band.

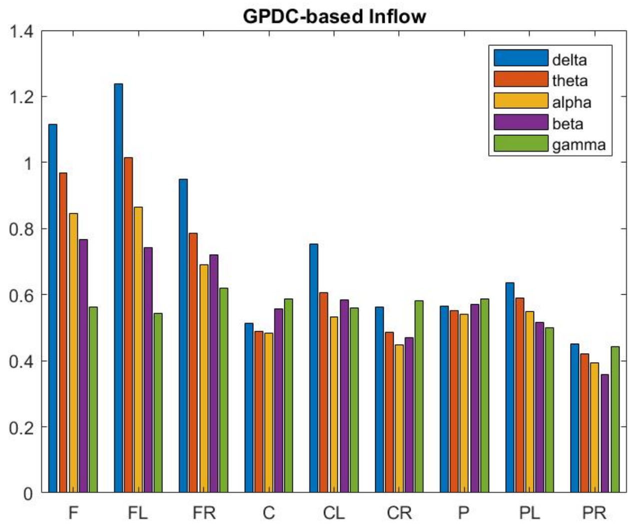

Figure 11: Total information inflow based on the GPDC for each diffent channels per frequency band.