Evaluation of various signal processing methods for brain connectivity

Proposal for master thesis
Student: Suraj Kumar Sanga, Supervisor: Su Kyoung Kim

1 Motivation

During cognitive activities, various brain areas interact with each other. Such brain connectivity can be studied at three diffrerent levels: a) anatomical connectivity, b) functional connectivity, and c) effective connectivity. *Anatomical connectivity* represents a physical connection in the brain. *Functional connectivty* is a measure of functional interactions between two or more brain regions computed as a bivariate process (use of two channels) or as a multivariate process (use of multiple channels). That means, the functional interaction can be realized either using statistical measures such as correlation and coherence or using the multivariate autoregressive (MVAR) model such as partial coherence. This functional interaction is "symmetrical" and "bidirectional" (X — Y) and thus provides no information about the influence of one channel on the other channel (X causes Y or Y causes X). In contrast, *effective connectivty* represents the causal directed influence between two or more brain regions. For example, the causal relationship between two channels (e.g. X causes Y) can be estimated using the multivariate autoregressive (MVAR) model, such as directed transfer function (DTF) and partial directed coherence (PDC), in which the current value of Y can be more accurately predicted from the past value of X. Such causal relationship is "asymmetrical" ($X \rightarrow Y$ or $X \leftarrow Y$). Measures of *functional* and effective *connectivty* can be realized by the parametric and the nonparametric methods. In this thesis, various non-parametric and parametric methods for measuring brain connectivity are evaluated (Details, see section 2 and Fig. 1).

2 State of Art

A classical measure of functional connectivity is the *coherence* which determines the relation between signal pairs as a function of frequency. As illustrade in Figure 2 (see left side), coherence can be represent by a direct connection (e.g. connection between X and Y without Z) or an indirect connection between two specific channels (e.g. connection between X and Y via Z). However, the connection is symmetrical (i.e. equally-weighted bidirectional: X — Y), not asymmetrical (i.e. unequally-weighted bidirectional or unidirectional: $X \rightarrow Y$). There are two types of coherences: single (i.e. coherence between two signal pairs) and multiple coherence (i.e. coherence between one signal and all other remaining signals). A single coherence for the specific cognitive activity can be found by the so called *partial coherence*, in which the "pure direct" connections between two specific channels become visible by eliminating the "indirect" connections. Another way to determine the relevant coherence for the specific cognitive activity is the use of *multiple coherence*. The strength of multiple coherence is computed at each individual channel. The channel which shows the strongst multiple coherence can be interpreted as the relevant channel for the specific cognitive activity. However, the properties of functional connectivity (i.e. symmetrical and equally-weighted bidirectional) implicates a limitation, in which the causal relationship between brain regions can not be illustrated.

Actually it is very challenging to determine the casual relationship between brain regions by drawing a directed (causal) information flow between brain regions (see Fig. 2 right side). The basic concept of such effective connectivity is the so called *granger causality* [1], which is relalized by using the multivariate autoregressive (MVAR) model (e.g. [2]). There are various methods for measuring the effective connectivity which is differently used depending on research goals (e.g. [3], [4]). For example, if we just know about the causal relationship between brain regions regardless whether the directedness between brain regions is direct

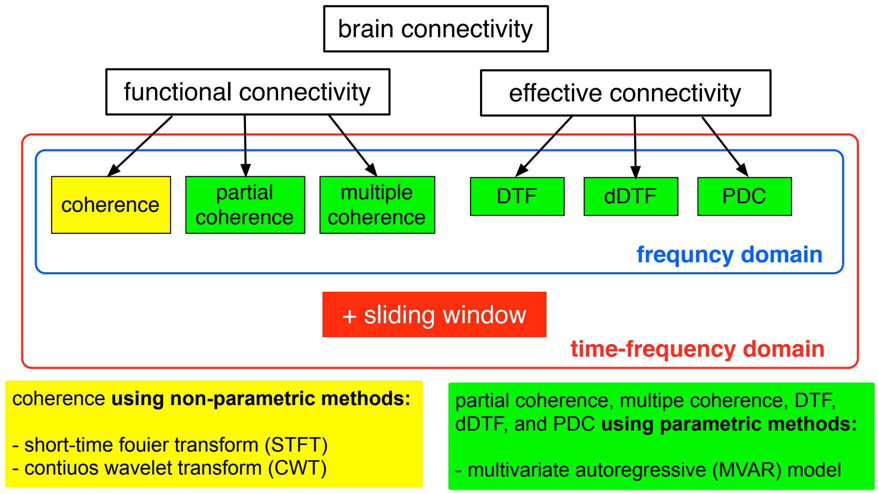

Figure 1: Various non-parametirc and parametric methods for measuring the brain conncetivity. The classical coherence can be revealed using both non-parametric (e.g. STFT/CWT) and parametric methods (e.g. MVAR model). Other methods for measuring the functional connectivity (partial coherence / multiple coherence) and the effective connectivity (e.g. directed transfer function (DTF)/dDTF/partial directed coherence (PDC)) are base on the parametric method.

or indirect (i.e. whether the effective connectivity is direct or indirect), the *directed transfer function (DTF)* is commonly used. However, it is unclear that the signal X is directly caused by Y or indirectly caused by Y (X is affected Y via Z). To represent only the ”direct” causal inforamtion flow between brain regions, the *directed DTF (dDTF)* can be used. For the dDTF, only ”direct” causal information flows are represented by eliminating the ”indirect (virtual)” causal information flows. Thus, the ”indirect” causal information flows are absent. Similar method for representing the pure direct causal inforamtion flows by distinguishing direct and indirect causal connection is the *partial directed coherence (PDC)*.

3 Goal and task

The goal of this thesis is to evaluate various measures of functional and effective connectivty (see Fig. 1). For that, firstly the methods should be implemented. Afterwards, the implemented methods should be tested on the simulated EEG data (e.g. [5]). Finally the implemented methods should be tested and evaluated on the real EEG data.

- Functional connectivity
  - coherence
  - partial coherence
  - multiple coherence
- Effective connecticity
  - directed transfer function (DTF)
  - directed DTF (dDTF)
  - partial directed coherence (PDC)

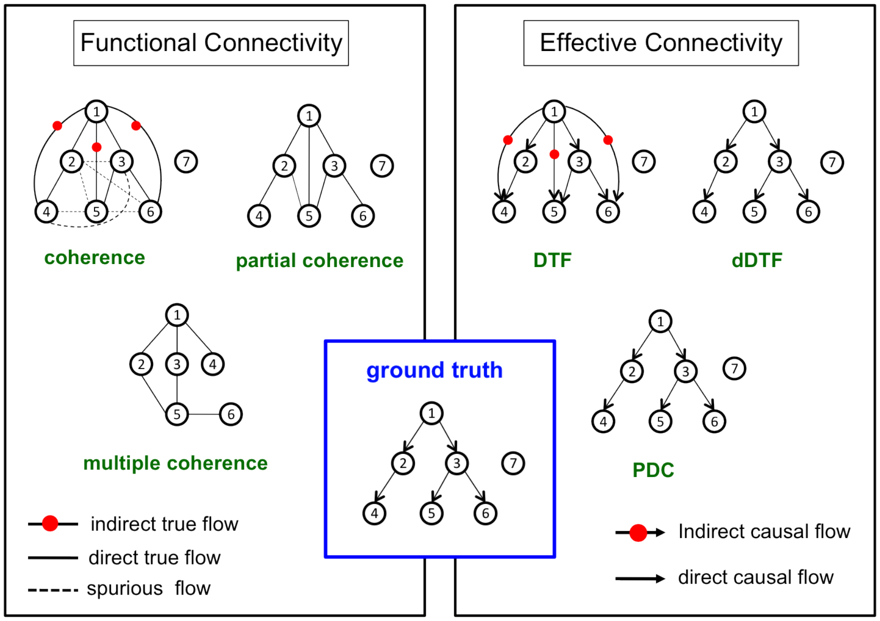

Figure 2: Comparison of the functional (left side: coherence, partial coherence, multiple coherence) and effective connectivity (right side: directed transfer function (DTF), directed DTF, partial directed coherence (PDC)).

References

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