Directed information structure in interregional cortical interactions in a visuomotor task

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Joseph T. Lizier[1,2], Jakob Heinzle[3], Annette Horstmann[4], John-Dylan Haynes[3,4], Mikhail Prokopenko[1,5]
[1]CSIRO ICT Centre, Sydney, [2]The University of Sydney, [3]Bernstein Center for Computational Neuroscience, Charité – Universitätsmedizin, Berlin, [4]Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, [5]The University of New South Wales, Sydney.

1. Introduction

We present a novel functional connectivity analysis of fMRI data, which is based on transfer entropy. The method allows us to identify the underlying directed information structure between brain regions, and how that structure changes according to behavioural conditions, e.g. in a manual tracking task.
The characteristics of the approach we present provide the following distinguishing features:

Characteristics of approach:
- Information-theoretical → Distinguished in identifying: • Nonlinear,
- Asymmetric → • Directional,
- Multi-variate → • Collective interactions.

2. Experiment

- Functional Magnetic Resonance Imaging (fMRI) EPI recorded while subjects (8) tracked a moving visual target on a computer screen with their right index finger.
- Tracking difficulty was altered between blocks 15 seconds.
- fMRI data was pre-processed and extracted for 16 regions active during the task

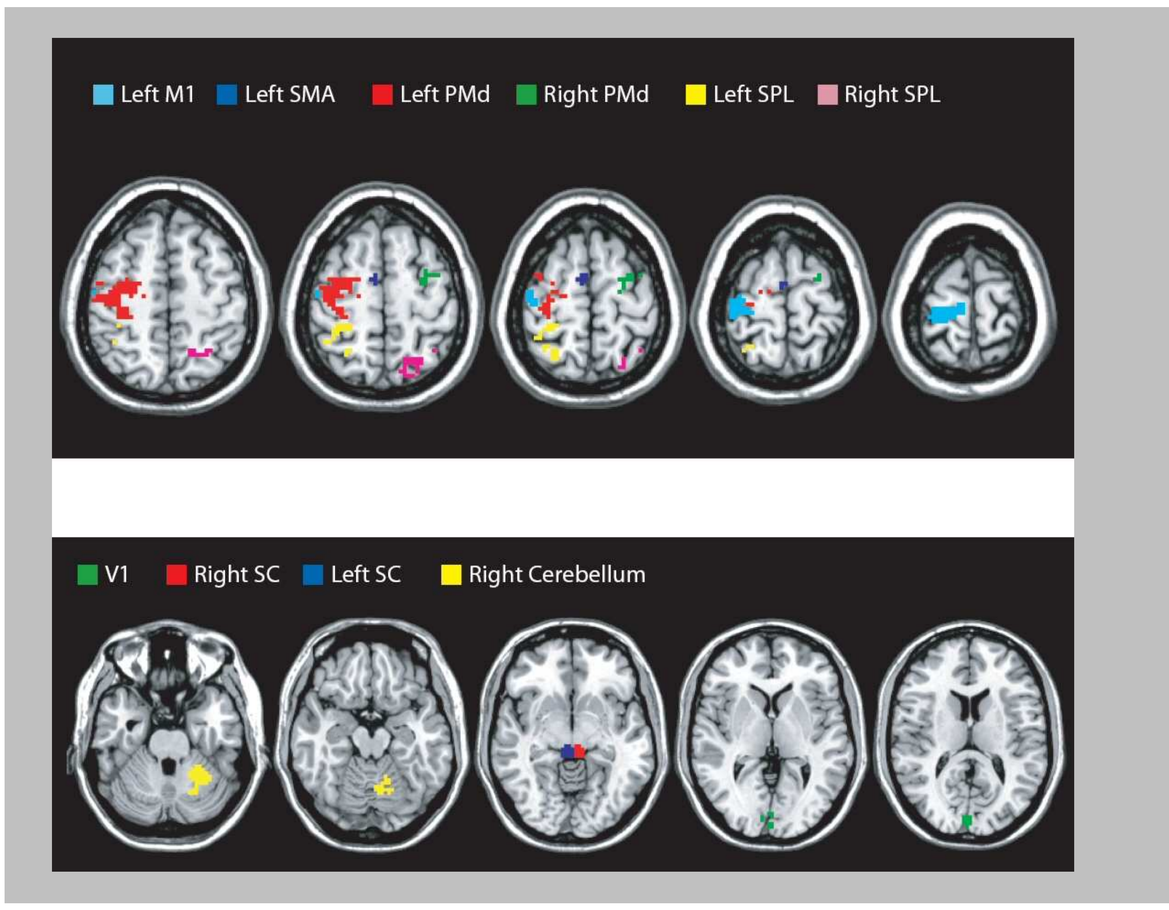

Figure 1: Regions for fMRI measurements in this experument: M1 – primary motor cortex, SMA – Supplementary motor area, PMd – pre-motor dorsal, SPL – superior parietal lobule, V1 – primary visual cortex, SC – superior colliculus

3. Analysis method: Transfer Entropy

- Average Info added by source about next state of destination that was not contained in destination's past [1] (mutual info of source and next state of dest condition on past of dest):

$$T_{Y\to X} = \sum_{u_n} p(u_n) \log \frac{p(x_{n+1}|x_n^{(k)}, y_n^{(l)})}{p(x_{n+1}|x_n^{(k)})}$$

$$u_n = (x_{n+1}, x_n^{(k)}, y_n^{(l)})$$

Extensions introduced here:
- to multivariate systems (fig 2)
- Interregional TE (ITE) = sum over subsets of *n* voxels in each region.
- Assessment of statistical significance [2] of ITE, and average ITE across subject group to infer interregional directed information structure.

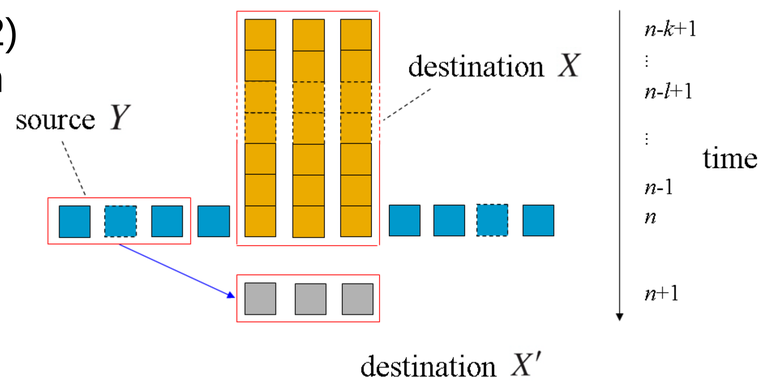

Figure 2: Multivariate transfer entropy

4. Results

Our method identifies:
1. A distinct 3-tier directed information structure (fig 3)
2. Increased coupling between movement planning and execution regions with task difficulty (fig 4).

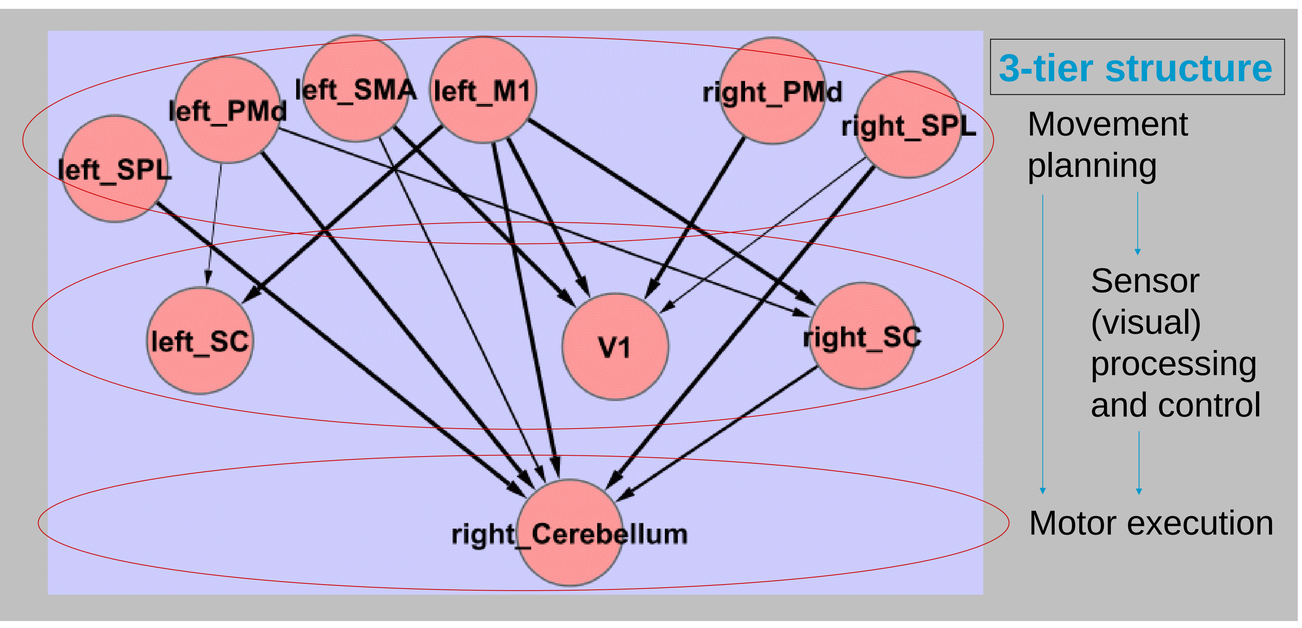

Figure 3: Directed information structure. Thickness of lines indicates significance against the null hypothesis of having no temporal relationship within a pair. (thickest: $p < 0.01$, thinnest: $p < 0.05$).

The presented method is useful for investigating interregional structure in fMRI studies, but could also be applied to other modalities such as electrophyisological multi-electrode array recordings.

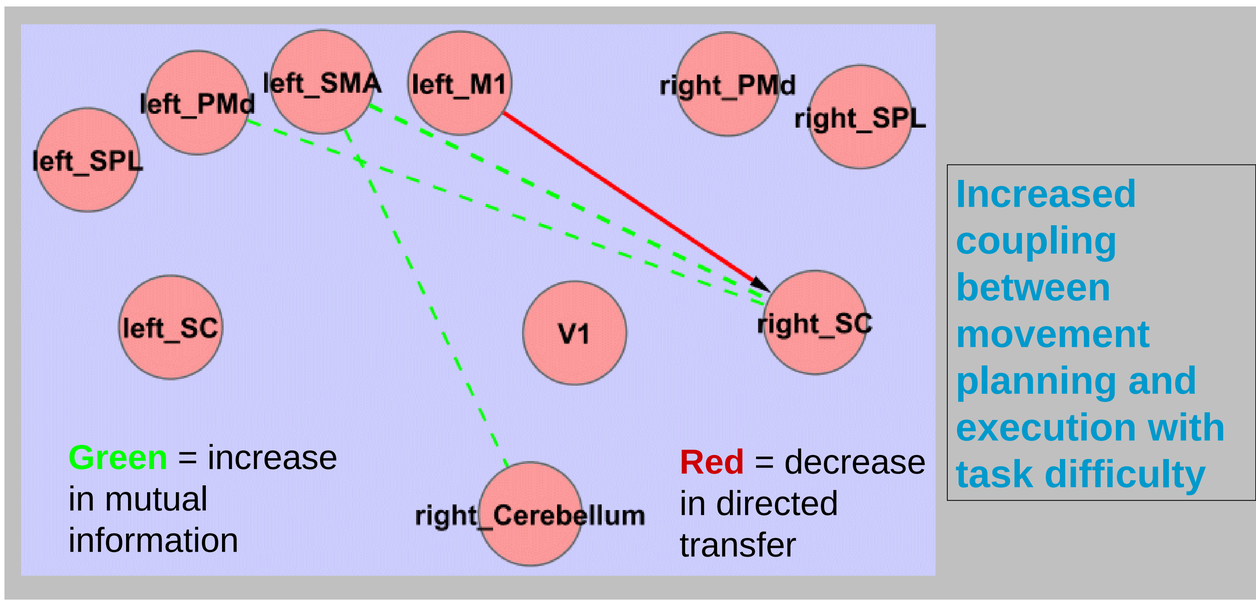

Figure 4: Connections with statistically significant (t-test, $p < 0.05$) correlation between information (transfer) and task difficulty.

References
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[3] Lizier JT, Prokopenko M, Zomaya AY: Local transfer entropy as a spatiotemporal filter for complex systems. Phys Rev E 2008, 77: 0261101-0261104

Further information
contact: Joseph Lizier
phone: +61 (0) 2 9372 4711
email: joseph.lizier at csiro.au
web: www.ict.csiro.au
www.csiro.au