

Infering Directed Graphs from Logistic Regression on Signatures

Thoughts about causality in dynamic systems.



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Introduction

This work takes its source in a neuroscience project :

*Can we separate subjects with **aphantasia** from other using only their electroencephalograms ?*

Aphantasia is a partial or full incapacity for **mental imagery**.

To study this question, neuroscientists have established a protocol (see Figure 2) based on **(previously seen) colors mental imagery**.

Classification

As classifier, we use the following model :

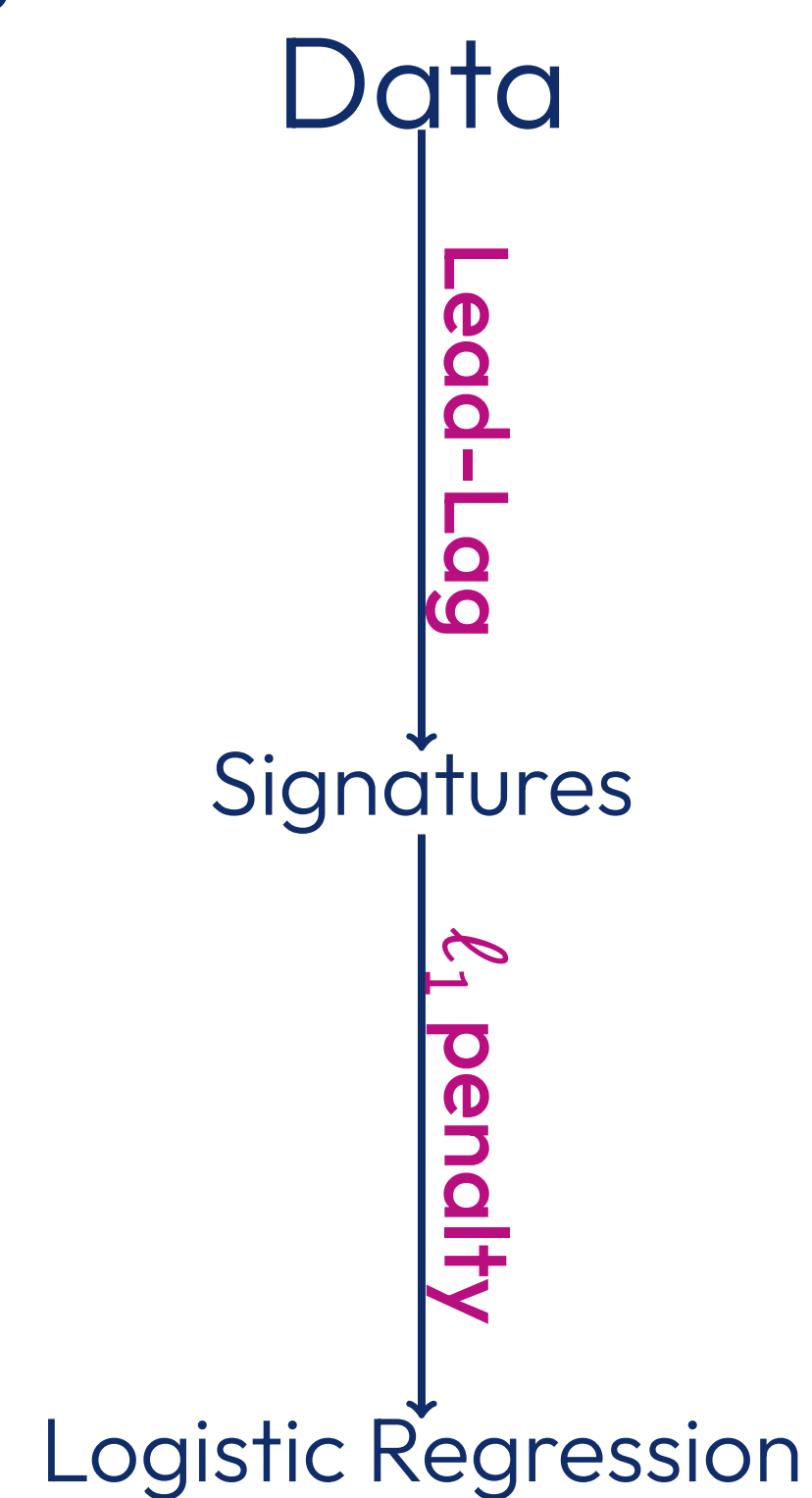


Figure - 1 : Full pipeline for classification.

Experience neuroscientifique

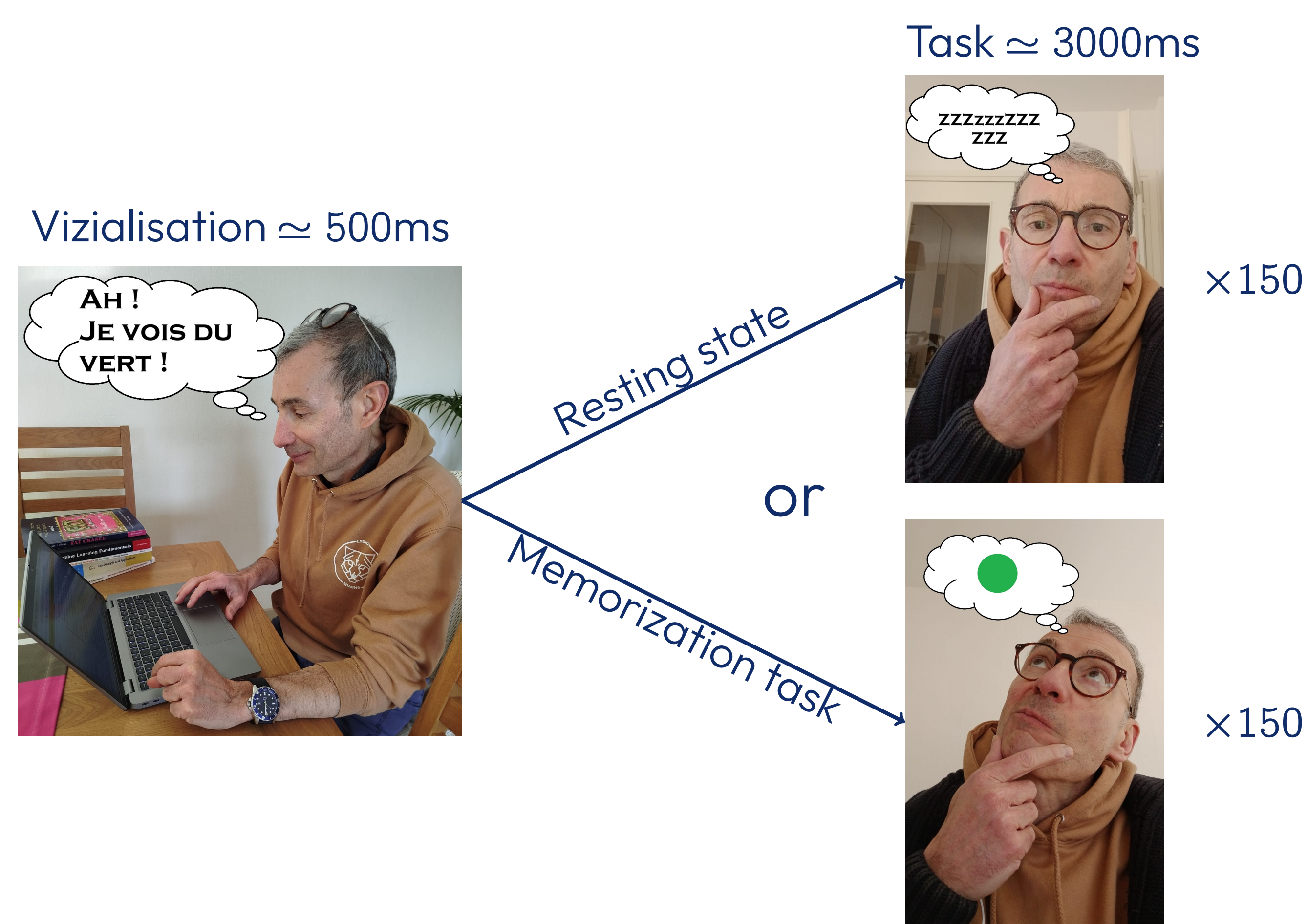


Figure - 2 : Stéphane Chrétien expérimentant le protocole neuroscientifique.

Stability

We assess the robustness of the inferred graphs by averaging adjacency matrices across cross-validation folds. Remarkably, edges are either consistently present or consistently absent across all folds, with no intermediate frequencies. This binary pattern highlights a high level of stability, indicating that the identified interactions are not driven by sampling variability but reflect robust, task-relevant structures.

Graphs inference methods.

We model multivariate EEG signals using **truncated path signature features**, which capture higher-order temporal interactions between channels. A logistic regression model with l_1 regularization is trained on these features, promoting **sparsity in the learned coefficients**.

The non-zero coefficients associated with **second-order signature terms are interpreted as directed interactions** between pairs of channels.

A thresholding step is then applied to retain **the most significant coefficients**, yielding a sparse directed graph that reflects **task-relevant information transfer patterns**.

Results

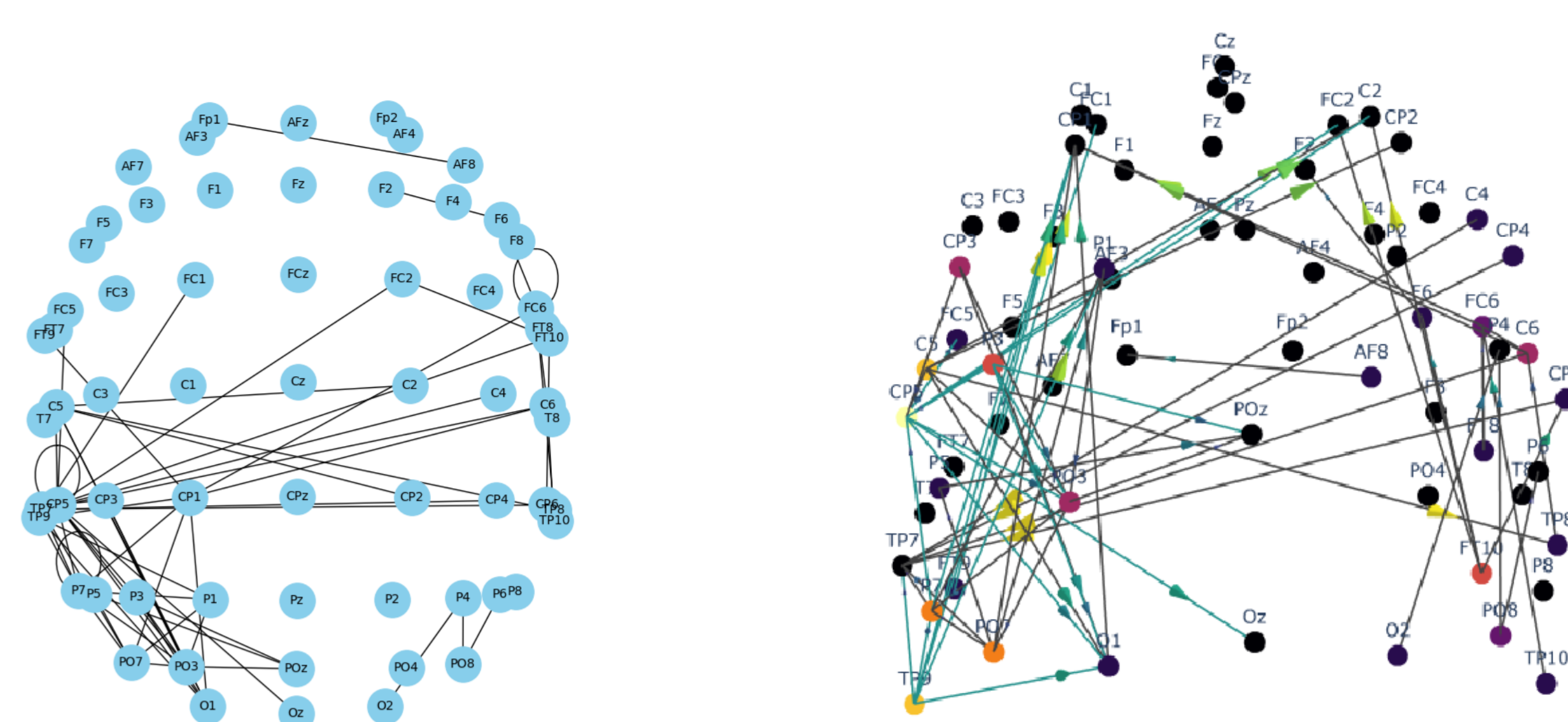


Figure - 3 : Graph infered on Mael Delem

The undirected graph shows links between **memory, language, auditive and vizualisation areas**. This is quite coherent as **subject has a low VVIQ** (Vividness Vizualisation Index Questionnaire) score.

The directed graphs shows a dynamics between the areas, **suggesting a memorization strategy** using language and audition to vizualise the proposed color.

Discussion

The inferred graphs **are not supposed to be causal**, as edges reflect discriminative dependencies rather than true causal effects. However, their direction captures asymmetric temporal interactions, providing an **intuitive notion of information flow**.

The observed patterns are consistent with neuroscientific expectations, suggesting task-relevant information transfer during memorization.

Références

Références principales :

- Giusti, C., Lee, D. (2025). *Iterated integrals and Population Time Series Analysis*. ArXiv.
- Le Clézio, D., Delem, M., Monzel, M., Plancher, G. (2026). *The impact of mental images on reasoning : A study on aphantasia*. Neuropsychologia.