Neural Communication Project
(Nov 2015 - Oct 2018)

“From neural coding to communication”

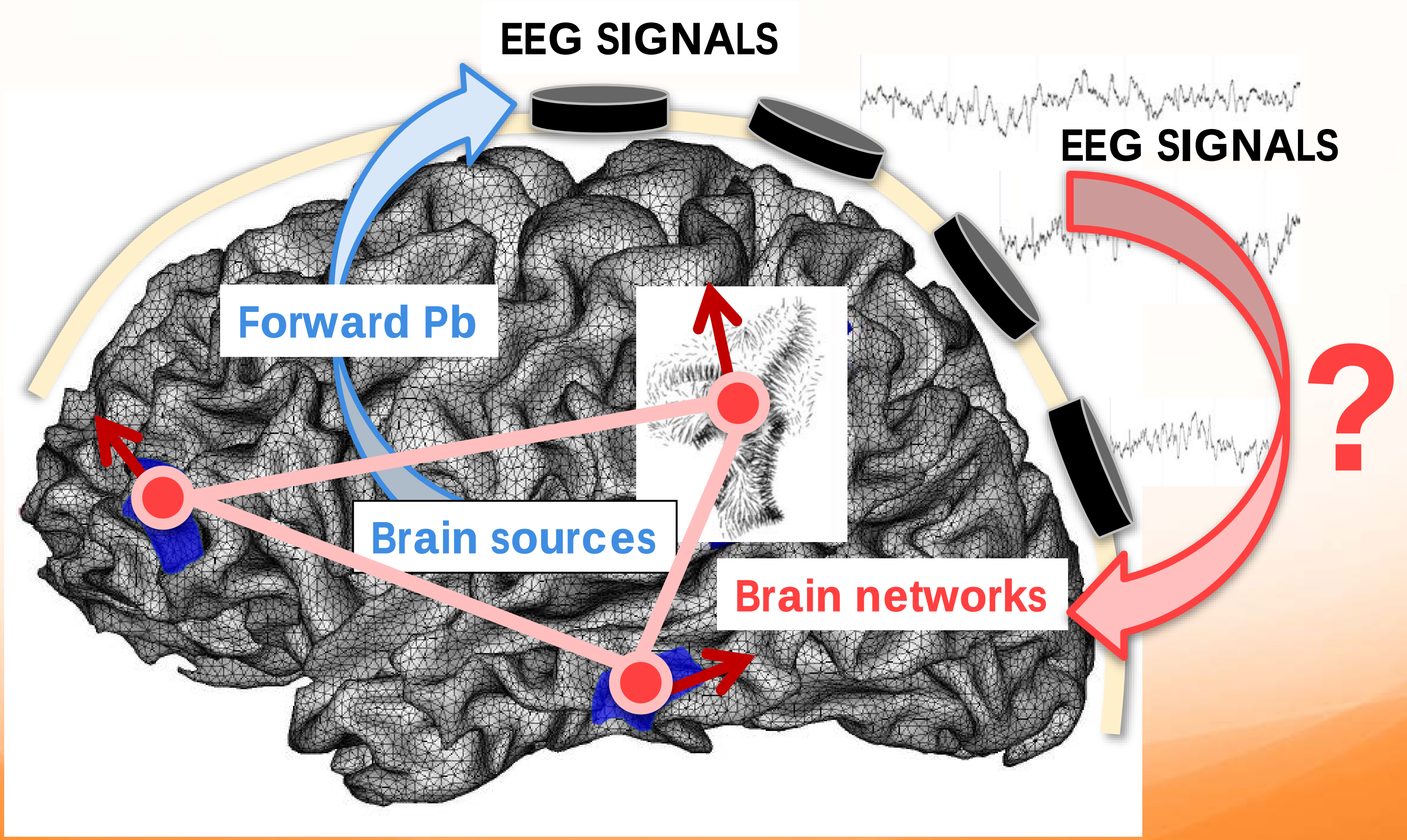
Lab-STICC

Laboratoire Traitement du Signal et de l'Image LTSI

Main achievements

Origin of the project: Neural coding (2012-15)

- **Context**: information processing in the brain, encoding/decoding processes
- **Objective**: to identify **networks** from **neuroimaging data (dense-EEG)**



Neural Coding: main result

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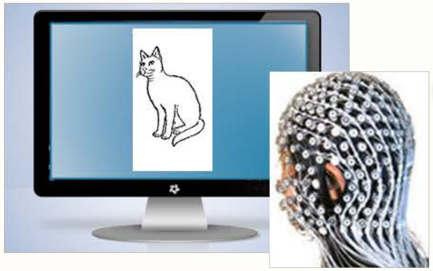
Stimulus onset → Visual perception, decoding, naming → **Naming**



EEG-based functional networks

⇕ ?

fMRI-based functional networks (literature review meta-analysis, same task)

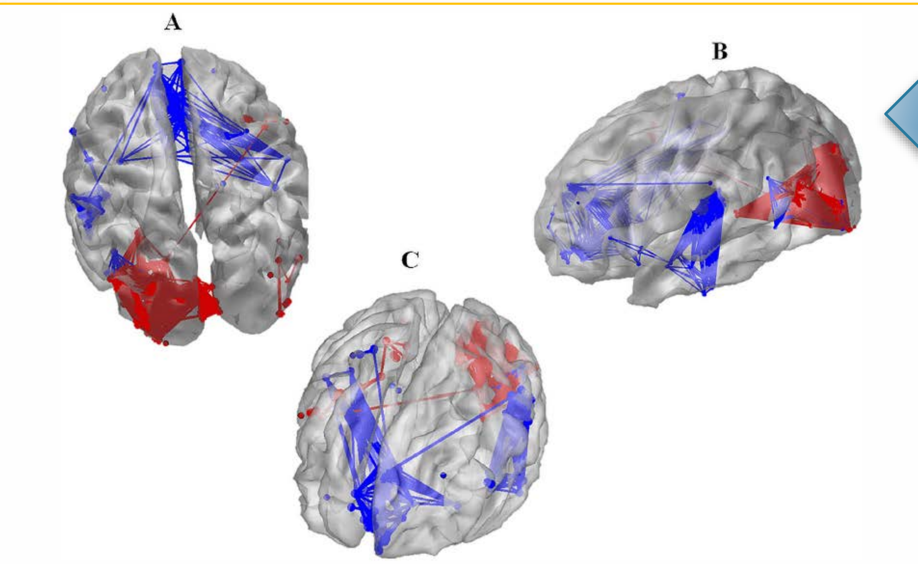


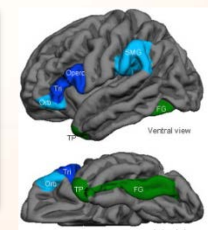
Figure 6. Typical example of the brain network identified using wMNE and sPLV in the picture recognition and naming task. A: lateral view B: Top view C: frontal view.

⇔

The neural regions sustaining object recognition and naming

PRICE[1], C. J. MOORE[1], G. W. HUMPHREYS[2], R. S. J. FRACKOWIAK[1] AND K. J. FRISTON[1]

[1] *The Wellcome Dept of Cognitive Neurology, Institute of Neurology, Queen Square, London WC1N 3BG, U.K.*
[2] *The School of Psychology, University of Birmingham, Edgbaston, Birmingham BT15 2TT, U.K.*



OPEN ACCESS Freely available online — PLOS | ONE

EEG Source Connectivity Analysis: From Dense Array Recordings to Brain Networks

Mahmoud Hassan[1,2*], Olivier Dufor[3], Isabelle Merlet[1,2], Claude Berrou[3], Fabrice Wendling[1,2]

2014. Citations: n=125 (GS)

Neural Communication: objective & WPs

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Objective: to develop methods for **tracking the spatiotemporal dynamics of brain networks**

- **WP1:** Project management

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- **WP2:** New approaches for **estimating current sources** in the brain (inverse problem) and for **generating dynamic networks** (graphs)

- **WP3: Experiments** (cognitive tasks)

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- **WP4: Graph signal processing**

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- **WP5 (education):** Contribution to the Master of Clinical Neurosciences. Lectures + training on neuroimaging data (EEG, fMRI) analysis.

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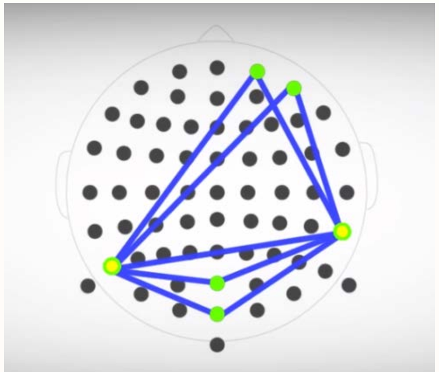
WP2. “EEG-based” high space/time resolution brain networks

Rupture technologique: connectivité de sources et réseaux « dynamiques »

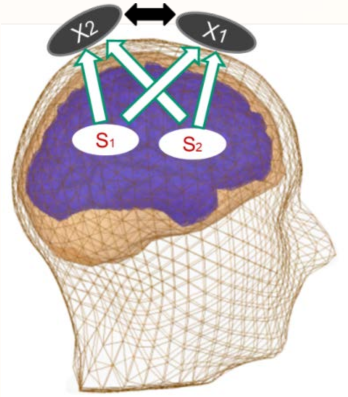
Dense-EEG

Classical method

« SENSOR space »



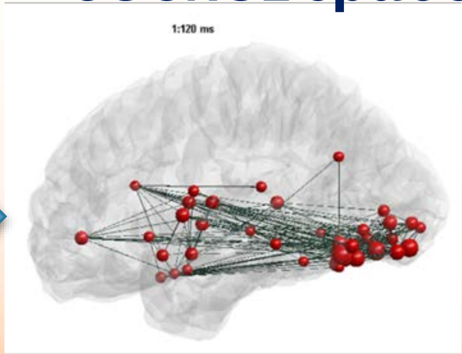
Volume conduction

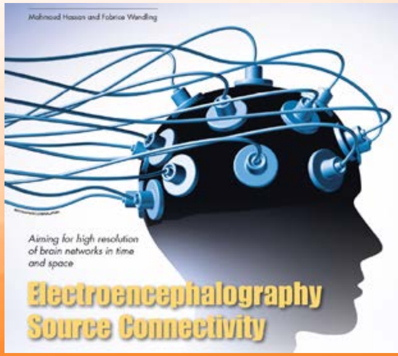


Source connectivity

- **Source reconstruction:** ill-posed inverse pb
- **Connectivity:** coupling between brain oscillations

« SOURCE space »





Hassan Wendling IEEE SPM 2018

WP3. Results: healthy subjects

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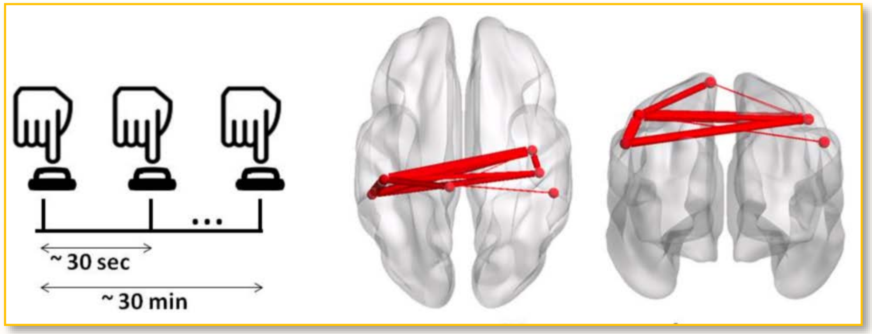
Detecting modular brain states in rest and task

A. Kabbara, M. Khalil, G. O'Neill, K. Dujardin, Y. El Traboulsi, F. Wendling and M. Hassan

Posted Online April 23, 2019

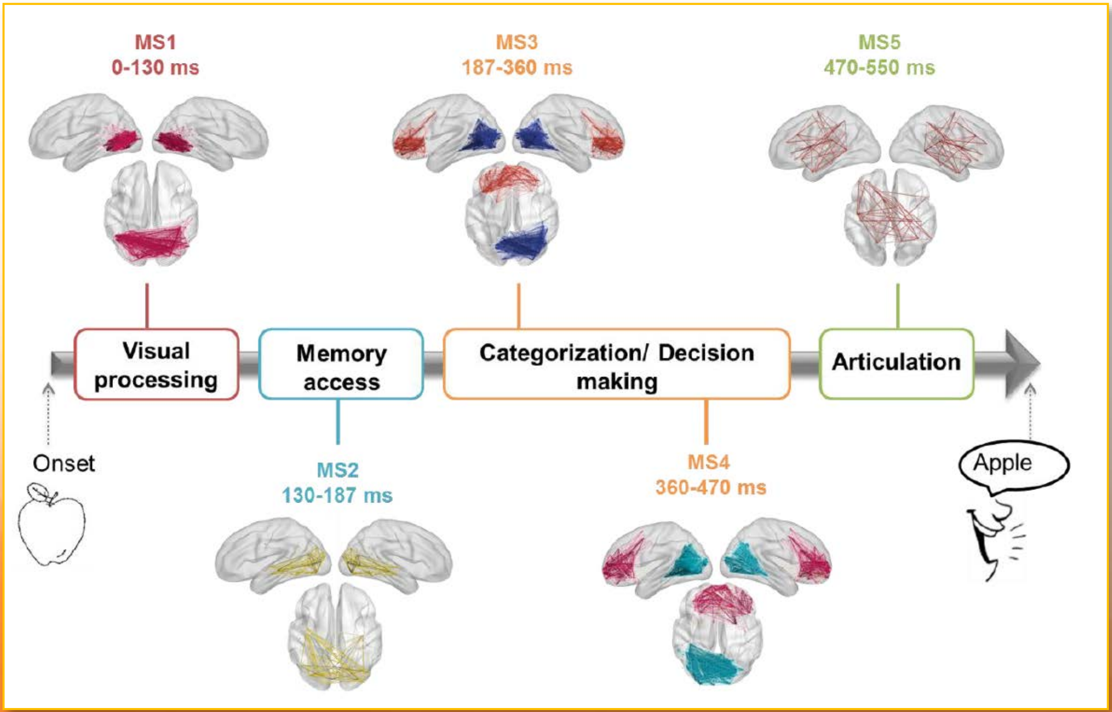
NETWORK NEURO SCIENCE

Motor Task



Detection of dominant brain networks during a given task

Picture naming task

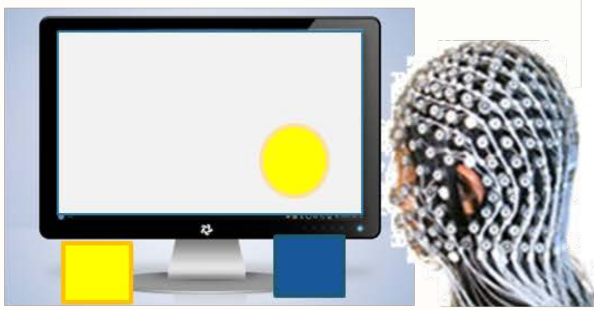


Tracking the dynamics of brain networks at sub-second time scale

WP3. Clinical application: Parkinson’s Disease

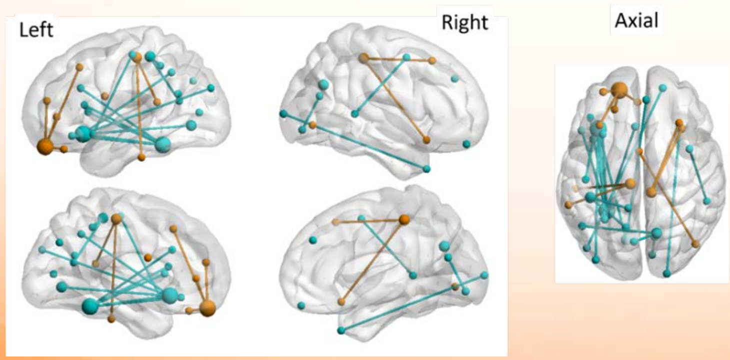
Motor Task

Stimulus onset (t=0 ms) → **Motor response (t=600 ms)**

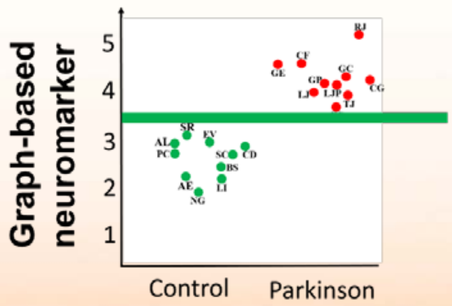


Dynamical analysis of (dys)functional networks

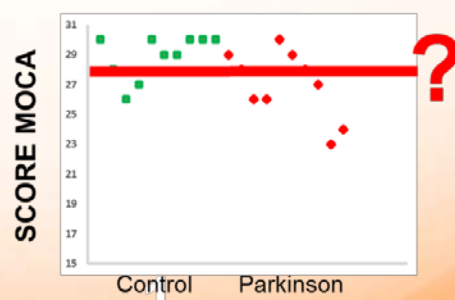
Time window: 300 – 400 ms



EEG source connectivity



Neuropsycho. tests



Hassan M., Chaton L., **Benquet** P., Delval A., Leroy C., Plomhause L., Moonen A.J.H., Duits A.A., Leentjens A.F.G., van Kranen-Mastenbroek V., Defebvre L., Derambure P., **Wendling** F., Dujardin K., «Functional connectivity disruptions correlate with cognitive phenotypes in Parkinson’s disease», ***NeuroImage: Clinical***, vol. 14, 591-601, 2017.

WP3. Clinical application: Epilepsy

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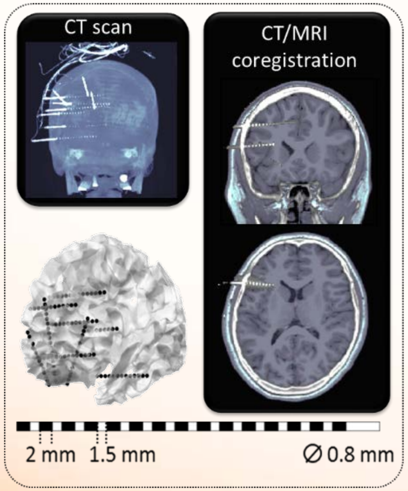

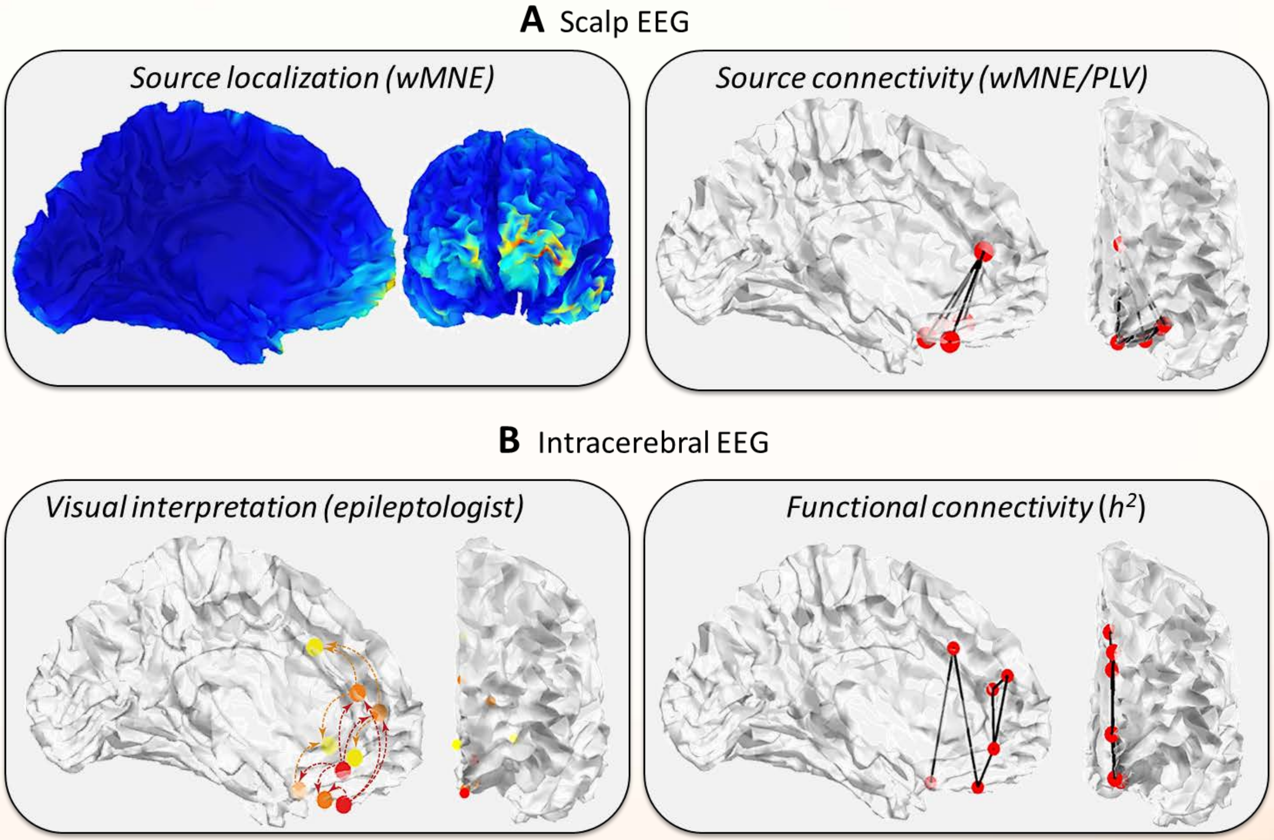

Hassan M., **Merlet** I., Mheich A., Kabbara A., Biraben A., Nica A., **Wendling** F., «Identification of interictal epileptogenic networks from dense-EEG », ***Brain Topography***, 1-17, 2017

ERC SyG – 2019

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Controlling epileptic brain networks…

- **Graph signal processing** (GSP) : an emerging field

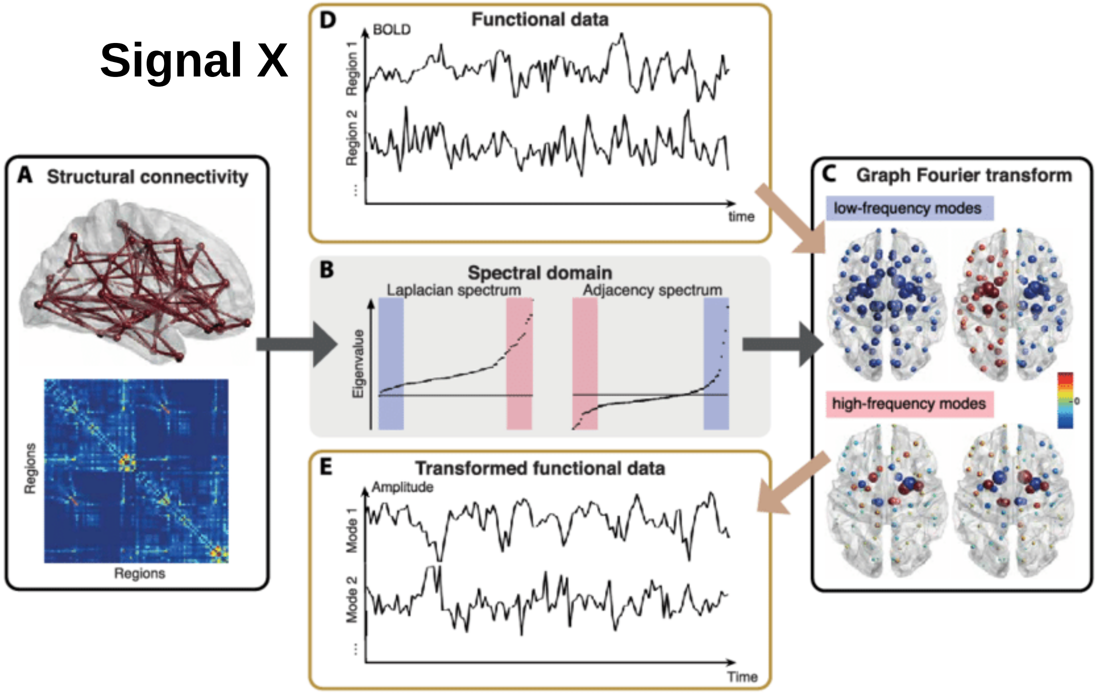
  Objective: Generalize signal processing (e.g. Fourier analysis) on irregular domains described by Graphs

  Rationale: Brain graphs formalized as a combination of functional or structural connectivity (A, D) + brain signals (X)

➔ Graph Fourier Transform

Signal X

Adjacency A
Degree D



Graph Laplacian
L = D-A

Eigenvectors U

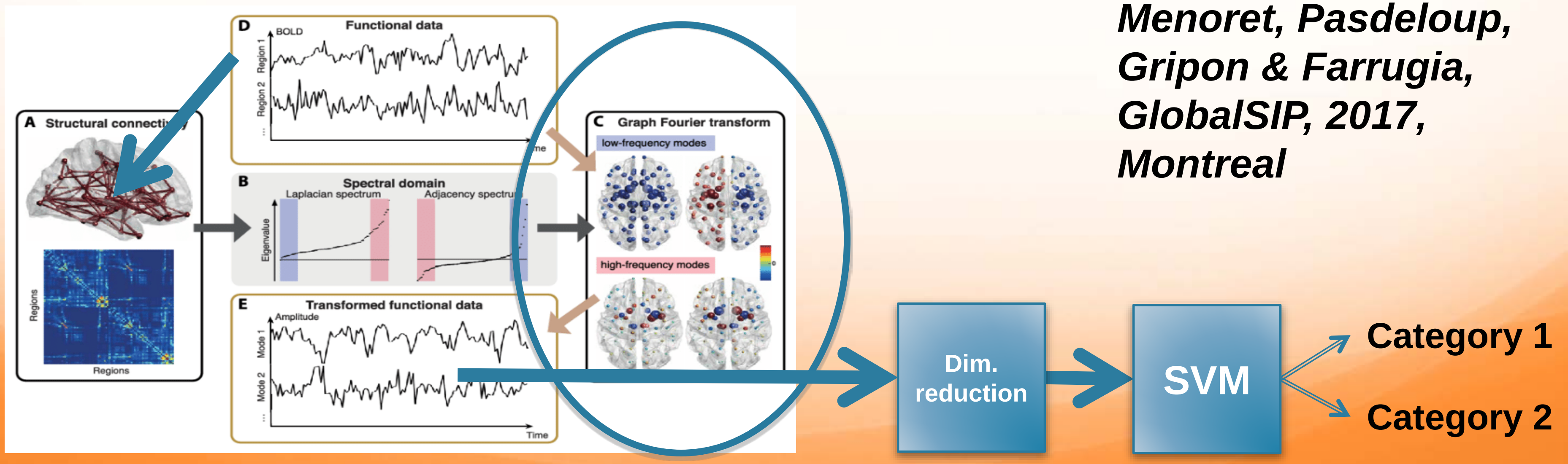
GFT(X) = UX

Adapted from Huang et al. 2018

WP4. Application to classification

- **Objective**: GSP to classify neuroimaging (EEG / fMRI) signals

- **Proposed method**:
  1. Parcellation of brain activity into ROIs (atlas)
  2. Definition of graphs using functional connectivity and / or distance between ROIs
  3. Feature extraction: Graph Fourier Transform (**GFT**) + dimensionality reduction methods (PCA, ICA, Graph Sampling)
  4. Classification of brain responses (supervised learning, SVM)



Menoret, Pasdeloup, Gripon & Farrugia, GlobalSIP, 2017, Montreal

WP4. Results on Haxby database

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- **Haxby dataset** (Haxby et al. 2001): fMRI data, visual stimulation using different image categories (faces, houses, cats, ...)

- **Goal** : retrieve the image category using bold signals

- **Approach**: Feature extraction using **GFT**, dimensionality reduction (**ICA**, **PCA**, Graph Sampling -**GS**-) followed by supervised learning.

Method	Face Vs House (%)	Face Vs Cat (%)
ROI+PCA	82.7	63.6
ROI+ICA	84.4	67.0
ROI+ANOVA	85.5	65.5
GFT+GS (Proposed)	**88.2**	**69**

➔ the combination of GFT with GS significantly increases classification accuracy

Menoret, Pasdeloup, Gripon & Farrugia, GlobalSIP, 2017, Montreal

WP4. PRODUCTION / VALORIZATION

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Publication

- GlobalSIP 2017 (Montréal)

Conferences, workshops, seminars

- Annual meeting of the Organisation for Human Brain Mapping in Geneva, June 2016
- Graph signal processing workshop in Pittsburgh, May 2017
- Graph signal processing workshop at EPFL, June 2018

Valorization and follow up projects

- Postdoc in the project (**Nicolas Farrugia**) is now Associate Prof. at IMT Atlantique, and further develops GSP for neuroimaging
- GSP Project (Brittany region SAD funding), 24 months postdoc, PI Nicolas Farrugia
- Multi-GSP Project (Brittany region SAD + Finistere funding), 24 months postdoc, PI Nicolas Farrugia
- New collaborations with Université de Montréal on applications of graph signal processing (1/2 PhD)

WP2/3. PRODUCTION / VALORIZATION

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Neural Communication

Publications (peer-reviewed articles)

1)Kabbara A, Mohamad K, O'Neill G, Dujardin K, El Traboulsi Y, Wendling F, Hassan M., « Detecting modular brain states in rest and task», ***Netw***

2)Rizkallah J, Annen J, Modolo J, Gosseries O, Benquet P, Mortaheb S, Amoud H, Cassol H, Mheich A, Thibaut A, Chatelle C, Hassan M, integration of EEG source-space networks in disorders of consciousness, ***NeuroImage: Clinical***, 2019.

3)Hassan M., Wendling F., «Electroencephalography source connectivity: toward high time/space resolution brain networks, ***IEEE Signal Proces***

4)Kabbara A., Eid H., El Falou W., Khalil M., Wendling F., Hassan M., «Reduced integration and improved segragation of functional brain networks in Alzheimer's disease», ***Journal of Neural engineering***, , 2018.

5)Rizkallah J., Hassan M., Kabbara A., Dufor O., Benquet P., Wendling F., «Dynamic reshaping of functional brain networks during visual object recognition», ***Journal of Neural engineering***, 2018.

6)Mheich A., Hassan M., Khalil M., Gripon V., Dufor O. and Wendling F., «SimNet: A Novel Method for Quantifying Brain Network Similarity », ***IEEE Transactions on Pattern Analysis and Machine Intelligence (TPAMI? IF=17)***, 2017. PDF

7)Kabbara A., El Falou W., Khalil M., Wendling F., Hassan M., «The dynamic functional core network of the human brain at rest », ***Scientific Reports***, 2017. PDF

8)Hassan M., Merlet I., Mheich A., Kabbara A., Biraben A., Nica A., Wendling F., «Identification of interictal epileptogenic networks from dense-EEG », ***Brain Topography***, 1-17, 2017. PDF

9)Hassan M., Chaton L., Benquet P., Delval A., Leroy C., Plomhause L., Moonen A.J.H., Duits A.A., Leentjens A.F.G., van Kranen-Mastenbroek V., Defebvre L., Derambure P., Wendling F., Dujardin K., «Functional connectivity disruptions correlate with cognitive phenotypes in Parkinson's disease», ***NeuroImage: Clinical***, vol. 14, 591-601, 2017. PDF

Neural Coding

10)Kabbara A., Khalil M., El Falou W., Hassan M., «Improving the P300-speller performance using brain functional connectivity », ***PLoS ONE***, *11*

11)Hassan M., Benquet P., Biraben A., Berrou C., Dufor O., Wendling F., «Dynamic reorganization of functional brain networks during picture nar

12)Hassan M., Shamas M., Khalil M., El Falou W., Wendling F., «EEGNET: An open source tool for analyzing and visualizing M/EEG connectome», ***PLoS ONE***, 10(9): e0138297, 2015. PDF

13)Mheich A., Hassan M., Khalil M., Berrou C., Wendling F., «A new algorithm for spatiotemporal analysis of brain functional connectivity», ***Journal of Neuroscience Methods***, 242, 77–81, 2015. PDF

14)Hassan M., Wendling F., «Tracking dynamics of functional brain networks using dense EEG», ***IRBM***, Volume 36, Issue 6, Pages 324–328, 2015.

15)Hassan M., Dufor O., Merlet I., Berrou C., Wendling F., «EEG source connectivity analysis: from dense array recordings to brain networks», ***PLoS ONE***, 9(8): e105041, 2014. PDF

Brevets :

Propriété intellectuelle : Université de Rennes 1 / INSERM – Gestion SATT Ouest Valorisation

- Brevet 1 – Princeps Analyse dynamique temporelle de l'évolution des réseaux de connectivité - (DV 2745) – « Dynamic reorganization of functional brain networks during picture naming »

- Inserm / Université de Rennes 1 – Priorité Fr n° 15/56586 du 10/07/15 – Inventeurs : F. Wendling / M. Hassan – Extensions nationales : Europe, USA

- Brevet 2 – Application de la méthode du Brevet 1 à la détermination d'un marqueur précoce de la maladie de Parkinson **-** (DV 3265) – « Procédé, dispositif et programme pour déterminer au moins un réseau cérébral impliqué dans une réalisation d'un processus donné » Inserm / Université de Rennes 1 – Priorités Fr n° 17/51585 et Fr n° 17/56378 du 06/07/17 – Inventeurs : F. Wendling / M. Hassan - Extension PCT en cours du 14/02/18

- Brevet 3 - Application de la méthode du Brevet 1 à la détermination d'un marqueur précoce de la maladie de Alzheimer - (DV3593) – « Reduced integration and improved segregation of functional brain networks in Alzheimer's disease » - Inserm / Université de Rennes 1 – Priorité EP n° 18155011.2 du 02/02/18 - Inventeurs : F. Wendling / M. Hassan / A. Kabbara – Renforcement du brevet sous priorité en cours

- Brevet 4 - Application de la méthode du Brevet 1 à la détermination des réseaux épileptogènes - (DV3527) - Détection des réseaux épileptogènes à partir de méthode EEG connectivité sources – Inserm / Université de Rennes 1 – Brevet EP en cours de dépôt – Juin 2018 - Inventeurs : F. Wendling / M. Hassan / A. Kabbara

Logiciel EEGNET (DV 2594) – Identification des réseaux cérébraux à partir de l'EEG

Dépôt APP : FR.001.300011.000.S.P.2015.000.31230 du 16/07/15

Déposants : Inserm / Université de Rennes 1 - Auteurs : Mahmoud Hassan, Fabrice Wending and Mohamad Shamas.

- Start-up Company: *Neurocort Technologies (June 18, 2019)*

The team

Operational Team

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A.Mheich, PhD
S.Yassine, MSc

Project Leader and CEO
JN. Brémont, MBA

Business Developer
Serge Kinkingnéhun, PhD

Scientific Committee

Scientific advisor
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Research director INSERM

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Head Epilepsy dept,
CHU Marseille

From innovation to economic valorization

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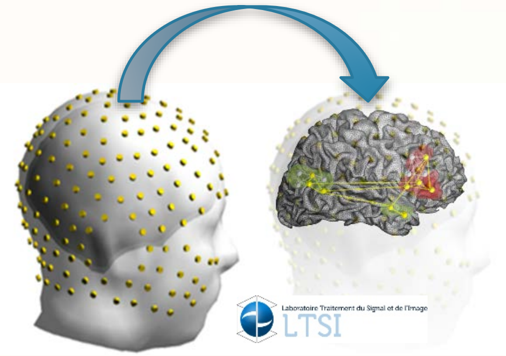

NEUROCORT TECHNOLOGIES

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New HR-EEG (2018)

Clinical studies