Dynamic source localization and functional connectivity estimation with multiple penalized state-space models

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Motivation

- Lack of efficient algorithms for solving large-scale state space models (**SSMs**).
- Solving the MEG/EEG brain source localization and functional connectivity (**FC**) problems with SSMs.
- Create semi-realistic large-scale brain models.

Background and Importance

- Source localisation and FC studies increase our understanding of brain information processing.
- Existing shortcomings of analytical tools bias our knowledge and limit potential applications.
- Better understanding of cognitive functions can be critical for developing new deep learning models.

Outcome

- Developed algorithms for solving the brain source localisation and FC problems simultaneously.
- This methodology has been demonstrated with large-scale simulations and real EEG data.

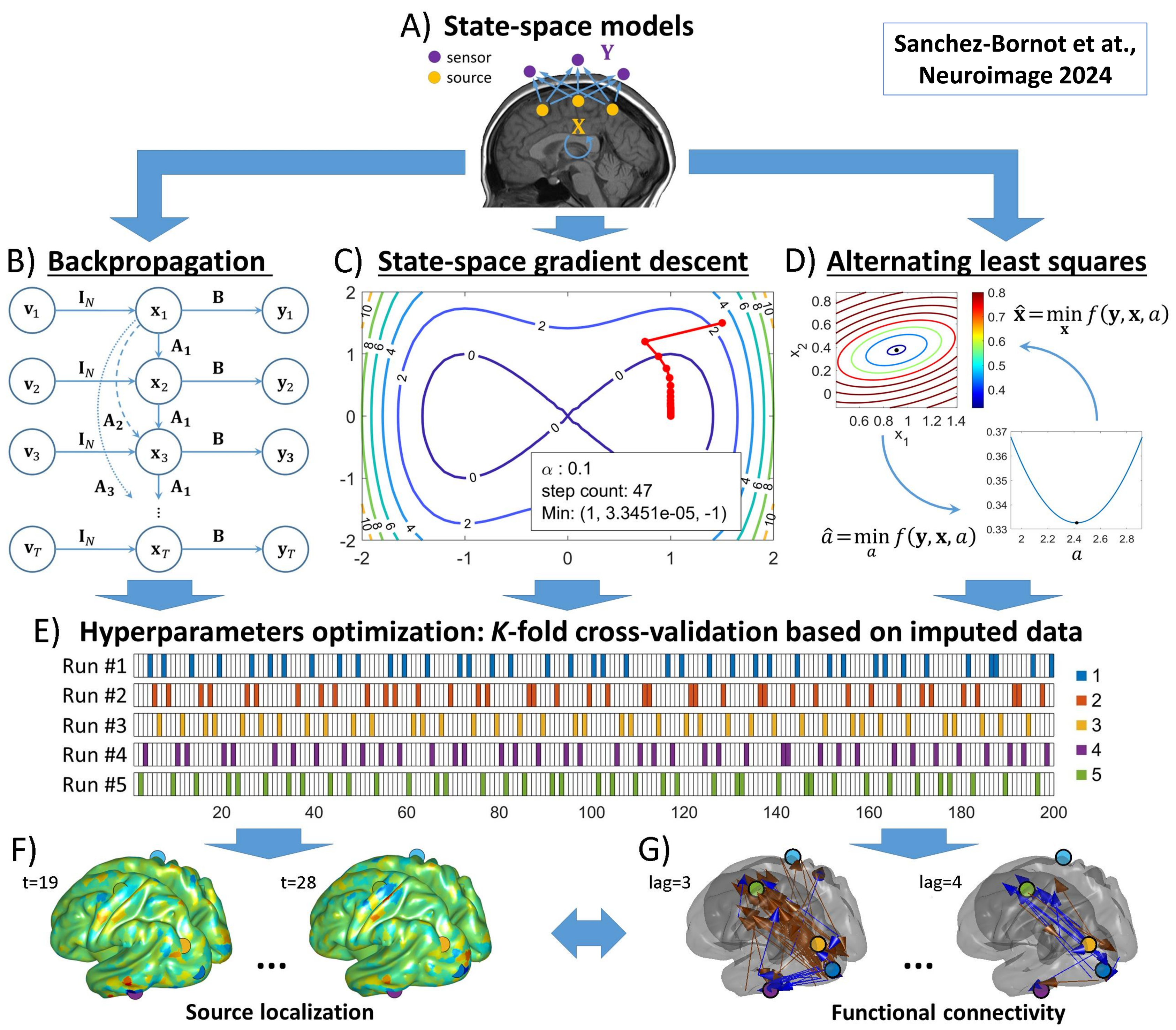
SSMs based on MVAR models:

(1) $\mathbf{y}_t = \mathbf{B}\mathbf{x}_t + \mathbf{w}_t$; with $\mathbf{w}_t \sim N(0, \sigma_o^2 \mathbf{I}_M)$,

(2) $\mathbf{x}_t = \sum_{p=1}^{P} \mathbf{A}_p \mathbf{x}_{t-p} + \mathbf{v}_t$; with $\mathbf{v}_t \sim N(0, \sigma_s^2 \mathbf{I}_N)$,

where $\mathbf{y}_t \in \mathbb{R}^{M\times 1}$ and $\mathbf{x}_t \in \mathbb{R}^{N\times 1}$ represent the measurements and source dynamics, $t = p+1, \ldots, T$, and $\mathbf{A}_p \in \mathbb{R}^{N\times N}$ denotes the neuronal communication, $p = 1, \ldots, P$.

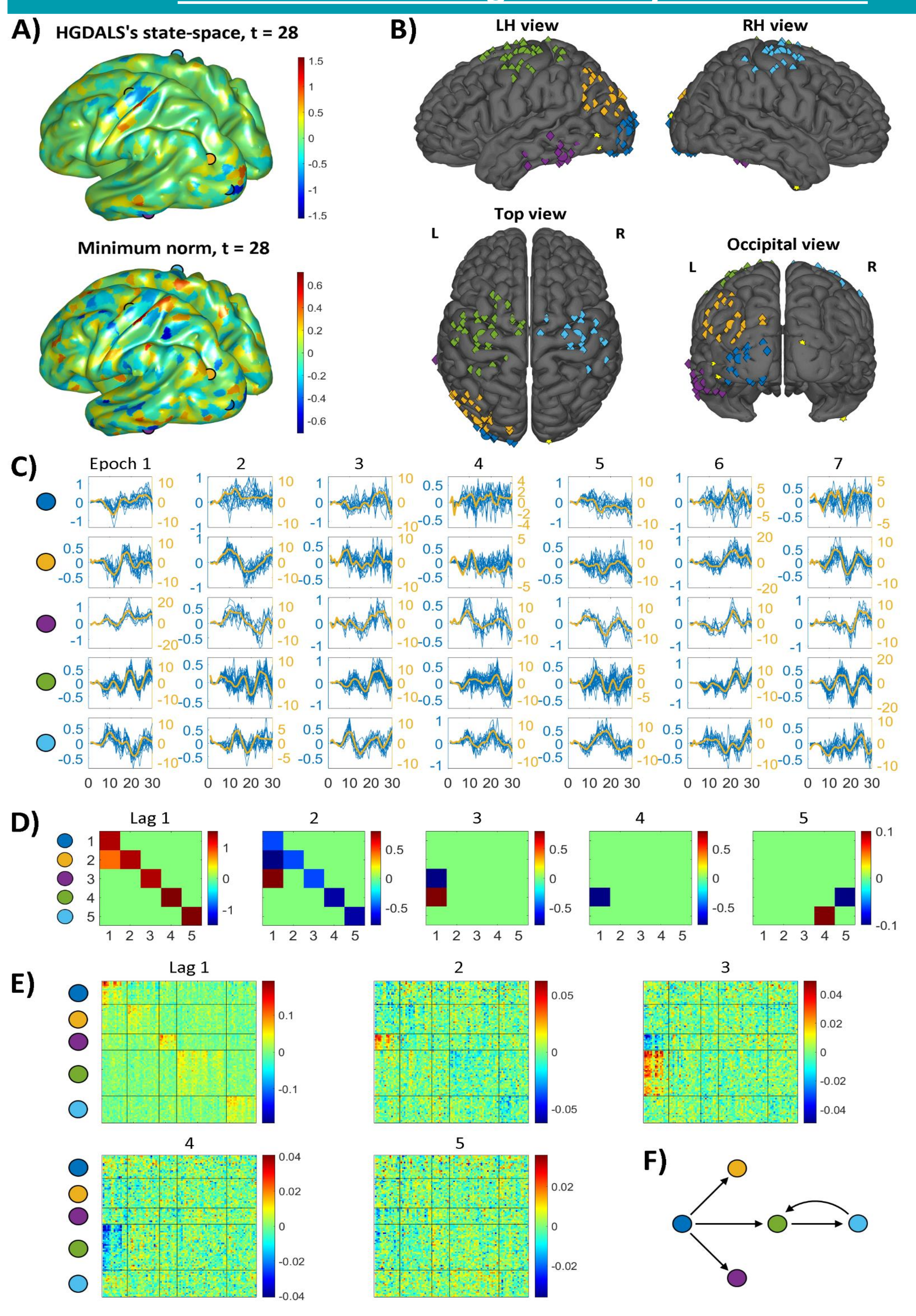
Sanchez-Bornot et al., Neuroimage 2024



A) Application to MEG/EEG data. **B-D)** Proposed to solve large-scale SSMs. **E)** Novel cross-validation approach to evaluate hyperparameters. **F-G)** Source and FC mappings from SSMs analysis. https://www.sciencedirect.com/science/article/pii/S1053811923006092

Results:

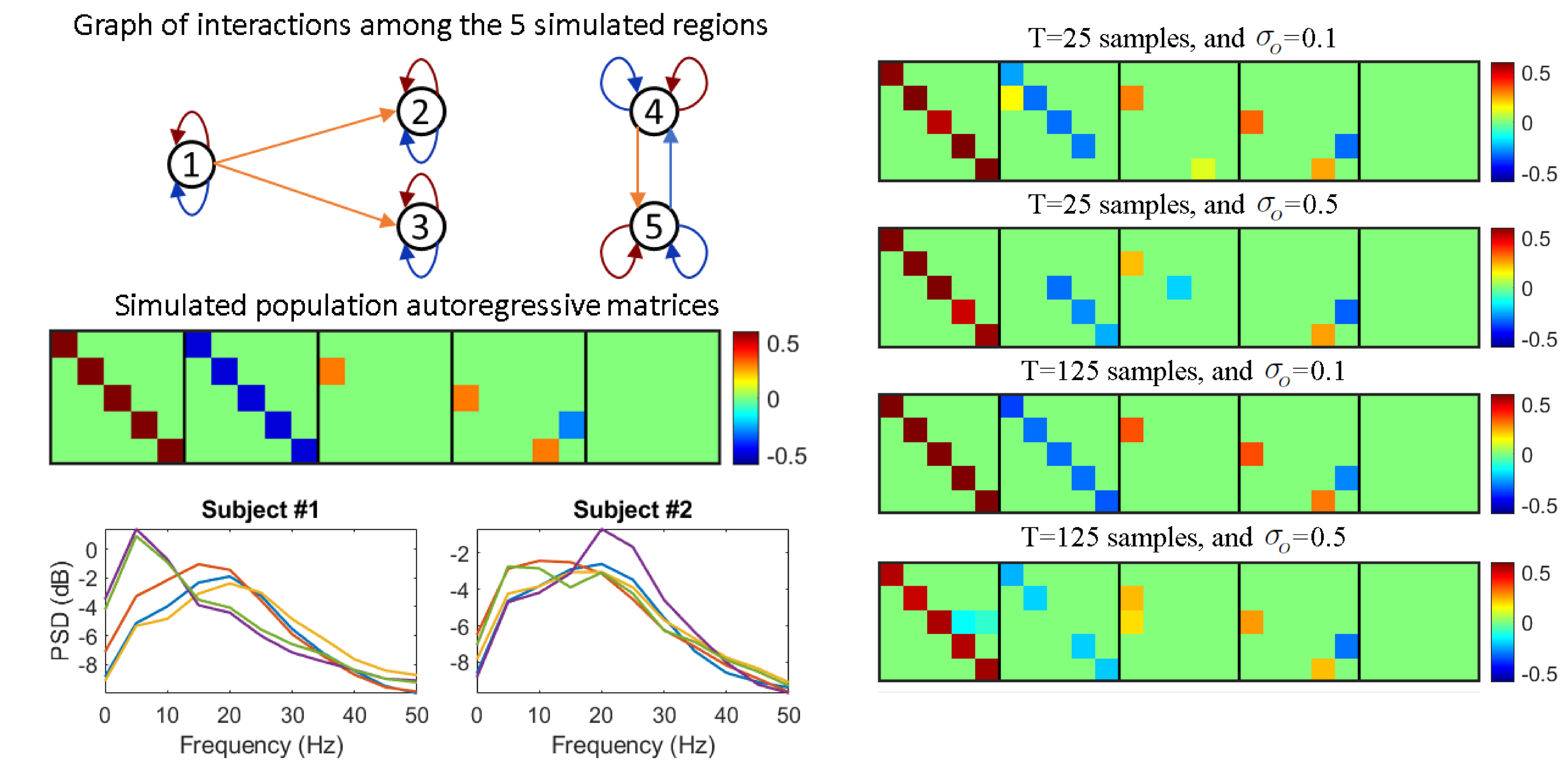
Validation with large-scale synthetic data



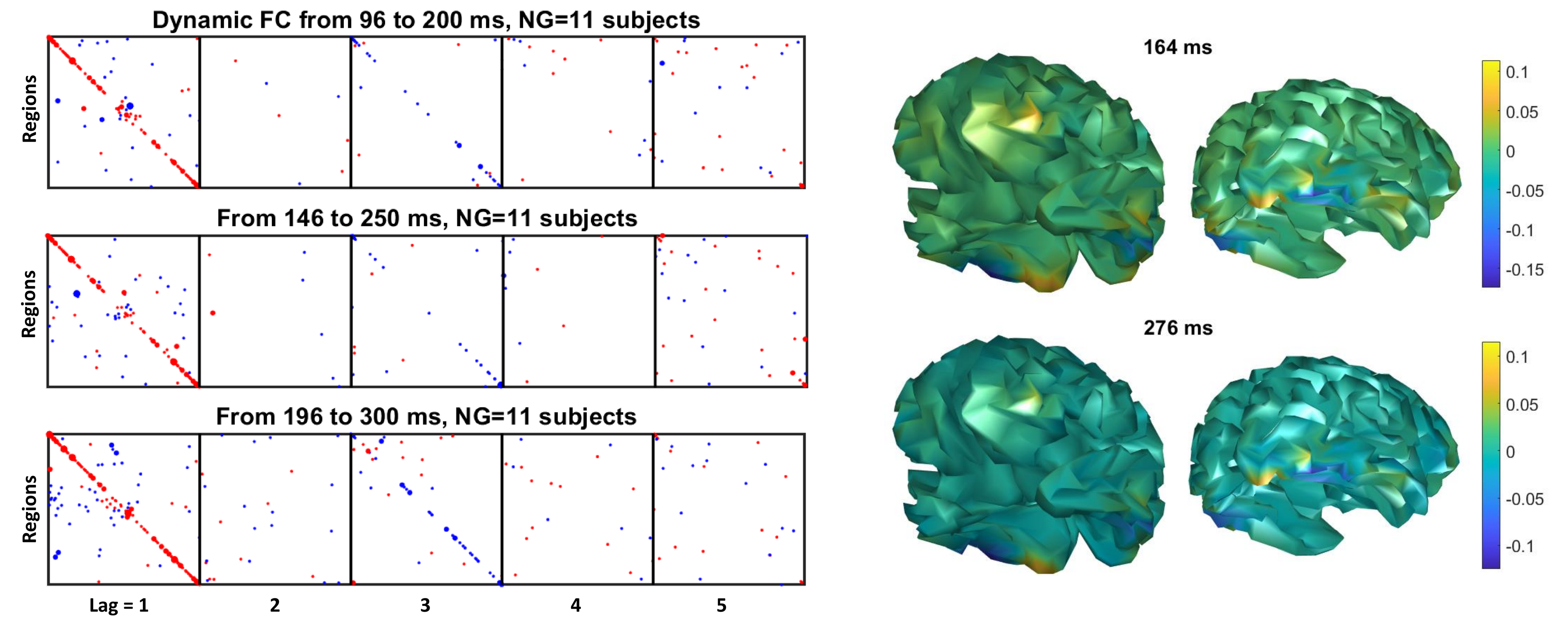
A-B) Brain source mapping. **C)** Estimation of sources time series. **D-F)** True and estimated FC maps.

Validation with simulated and real (population) EEG data

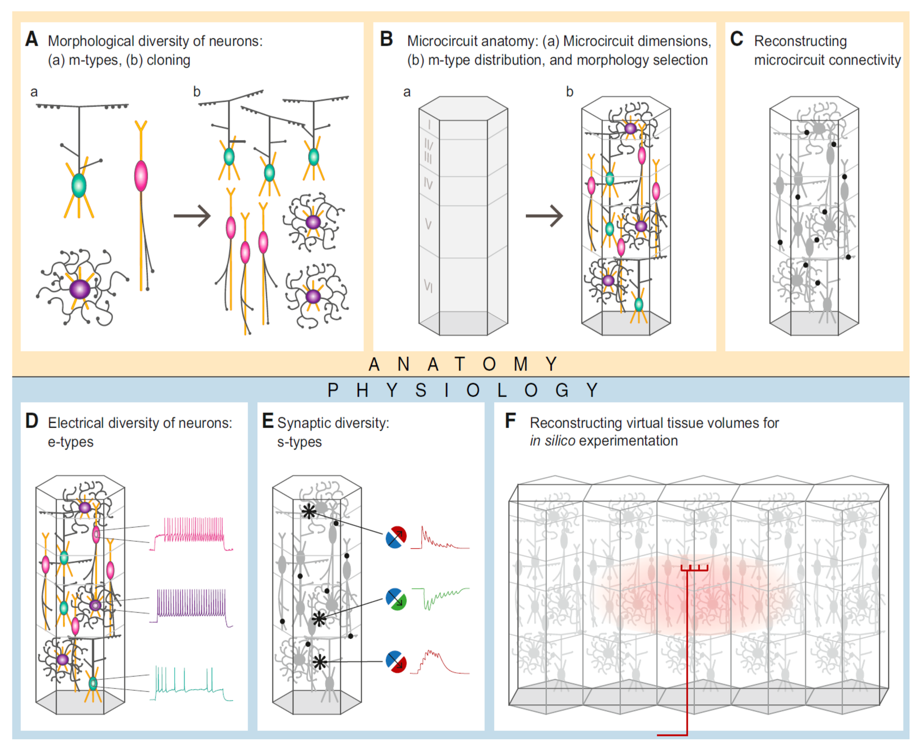
1. **We simulated a population of 13 individuals with dynamic created for five regions and random FC weights:**

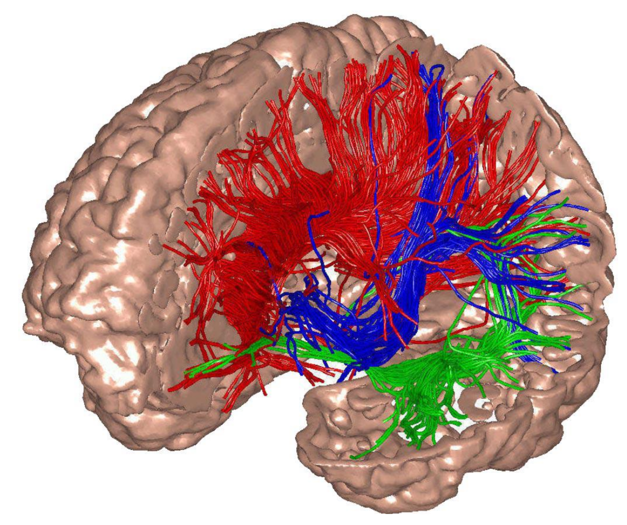


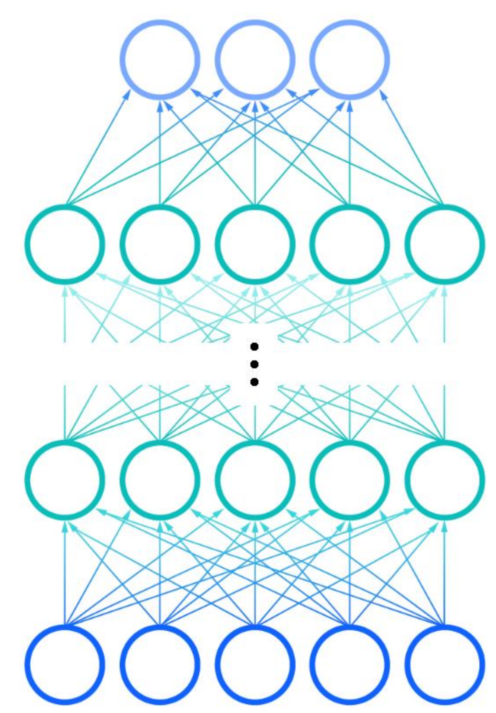
2. **Analysis of the Wakeman and Henson's MEG/EEG dataset with multiple penalized state space models:**



What's next? AI/Brain-inspired models capable of generating synthetic data (e.g., spiking rate, ECoG)







Left: Markram's cytoarchitectonic.
Middle: Izhikevich's model.
Right: Deep learning model

A feasible brain model must combine "practical" biological realism with "usefulness" to solve pattern recognition tasks, i.e., based on semi-realistic brain architectures (with well-known regional networks and functions) as framework.

References:

Markram, H., et al. (2015) "Reconstruction and simulation of neocortical microcircuitry." Cell 163.2, 456-492.
Izhikevich, E., and Edelman G. (2008) "Large-scale model of mammalian thalamocortical systems." PNAS, 3593-3598.
Sanchez-Bornot, J., et al. (2023) Dynamic Source Localization and Functional Connectivity... ICASSP2023.
Sanchez-Bornot, J., et al. "Solving large-scale MEG/EEG source localization ... using state-space models." Neuroimage (2024).

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