Dynamic source localization and functional connectivity estimation with state-space models: preliminary feasibility analysis

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ICASSP 2023
4 - 10 JUNE, RHODES ISLAND, GREECE

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 (twin digital) 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

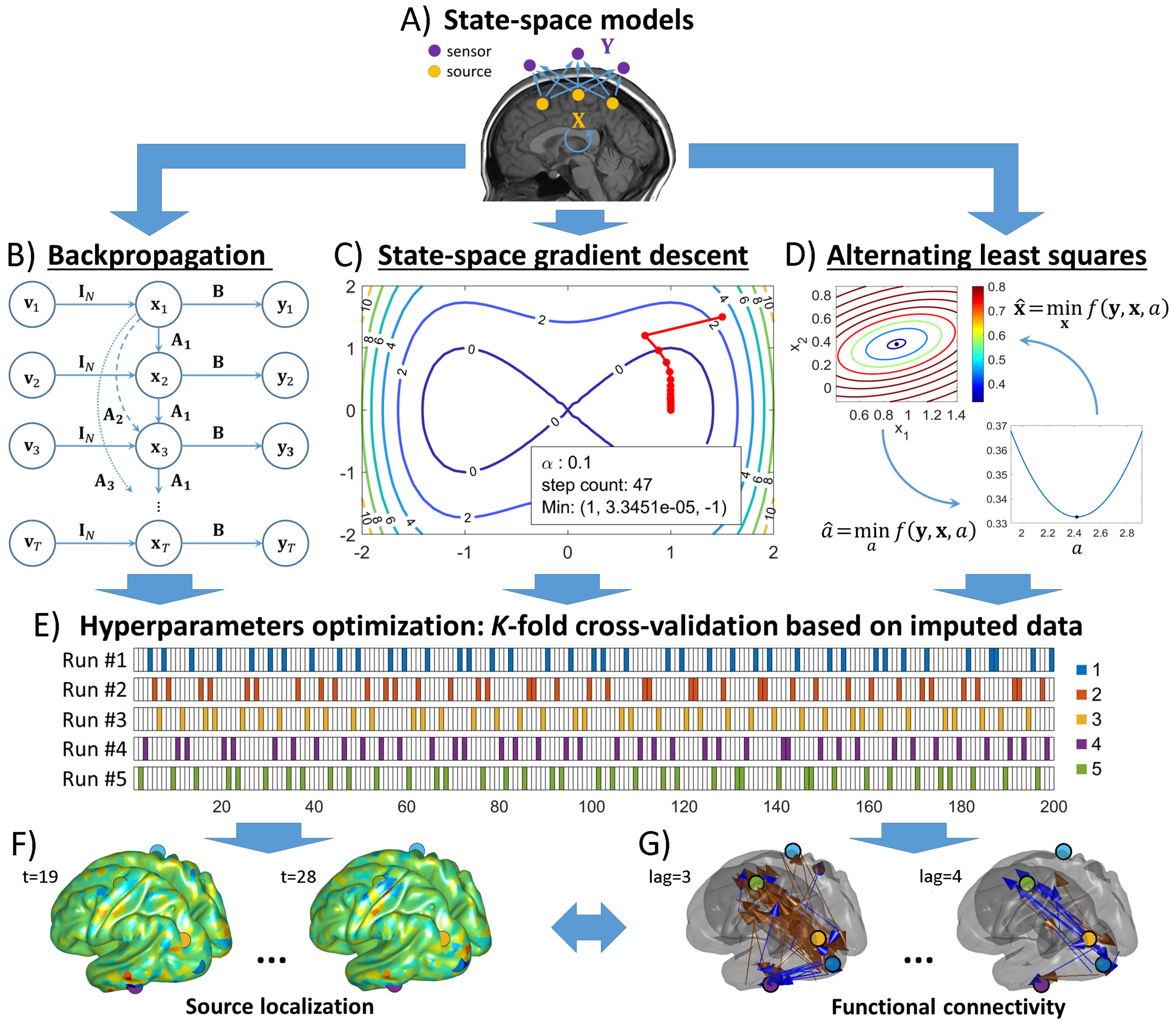
- Developed algorithms for solving the brain source localisation and FC problems simultaneously.
- This methodology has been demonstrated with large-scale simulations and real EEG data.

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 $\mathbf{v}_t \sim N(0, \sigma_s^2 \mathbf{I}_N)$,

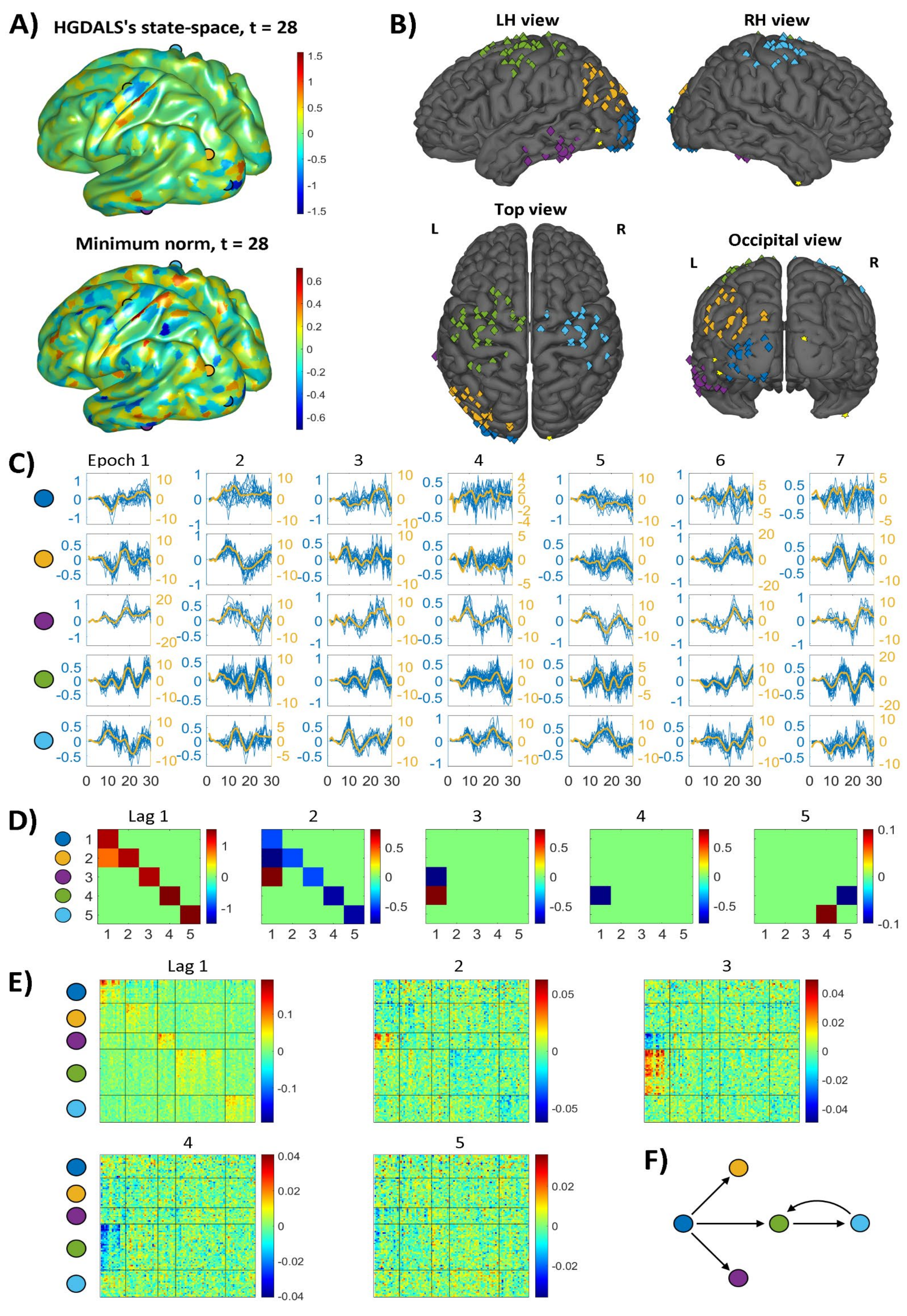
where $\mathbf{y}_t \in \mathbb{R}^{M\times 1}$ and $\mathbf{x}_t \in \mathbb{R}^{N\times 1}$ represent the measurements and source dynamics, $t = p+1, \ldots, T$, and $\mathbf{A}_p \in \mathbb{R}^{N\times N}$ denotes the neuronal communication, $p = 1, \ldots, P$.



A) Application to MEG/EEG data. **B-D)** Methods proposed to solve large-scale SSMs. **E)** Cross-validation approach to evaluate regularization parameters. **F-G)** Source and FC mappings derived from SSMs analysis. https://arxiv.org/pdf/2208.12854 **(preprint)**

Results:

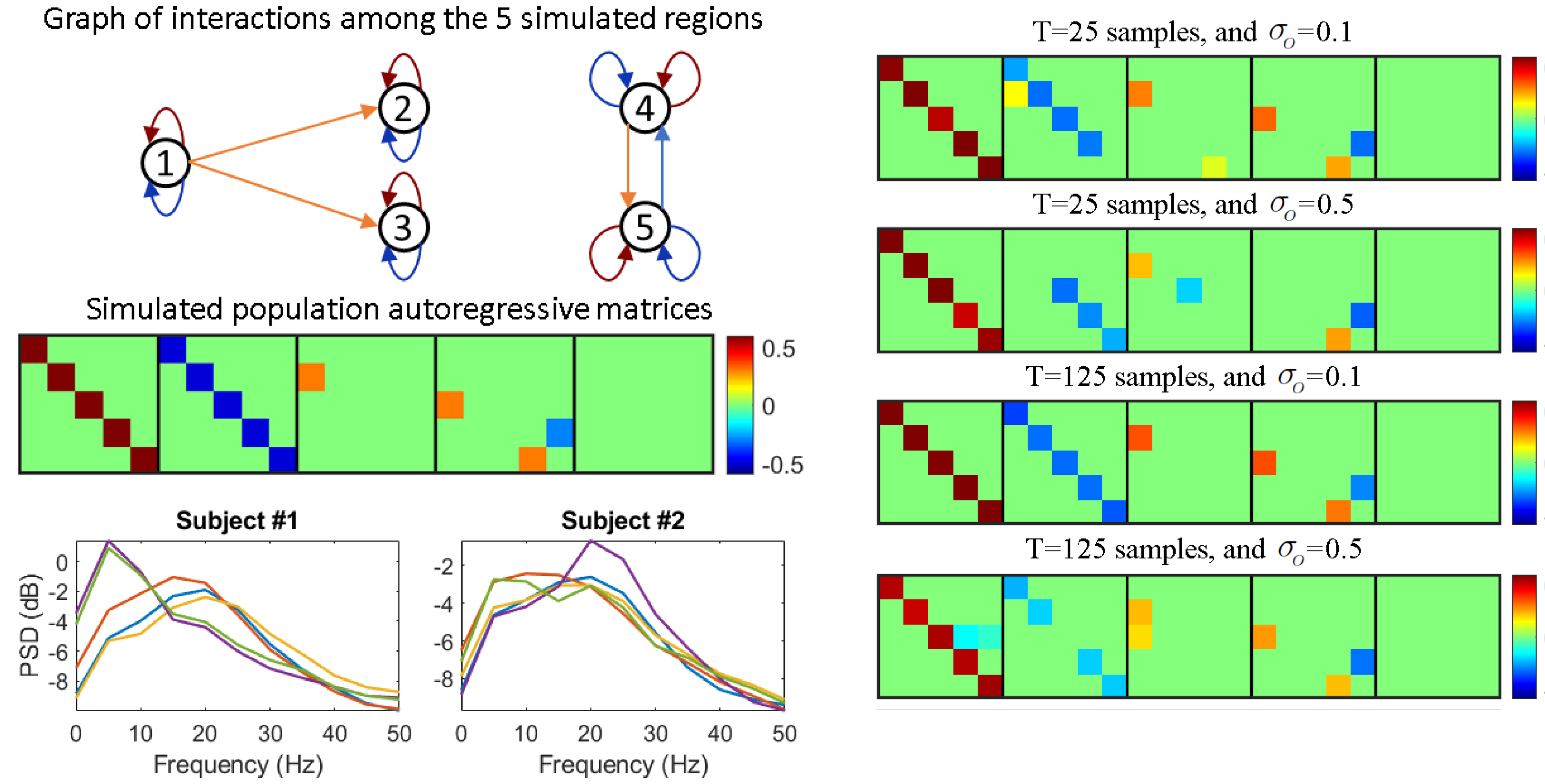
Validation with large-scale synthetic data



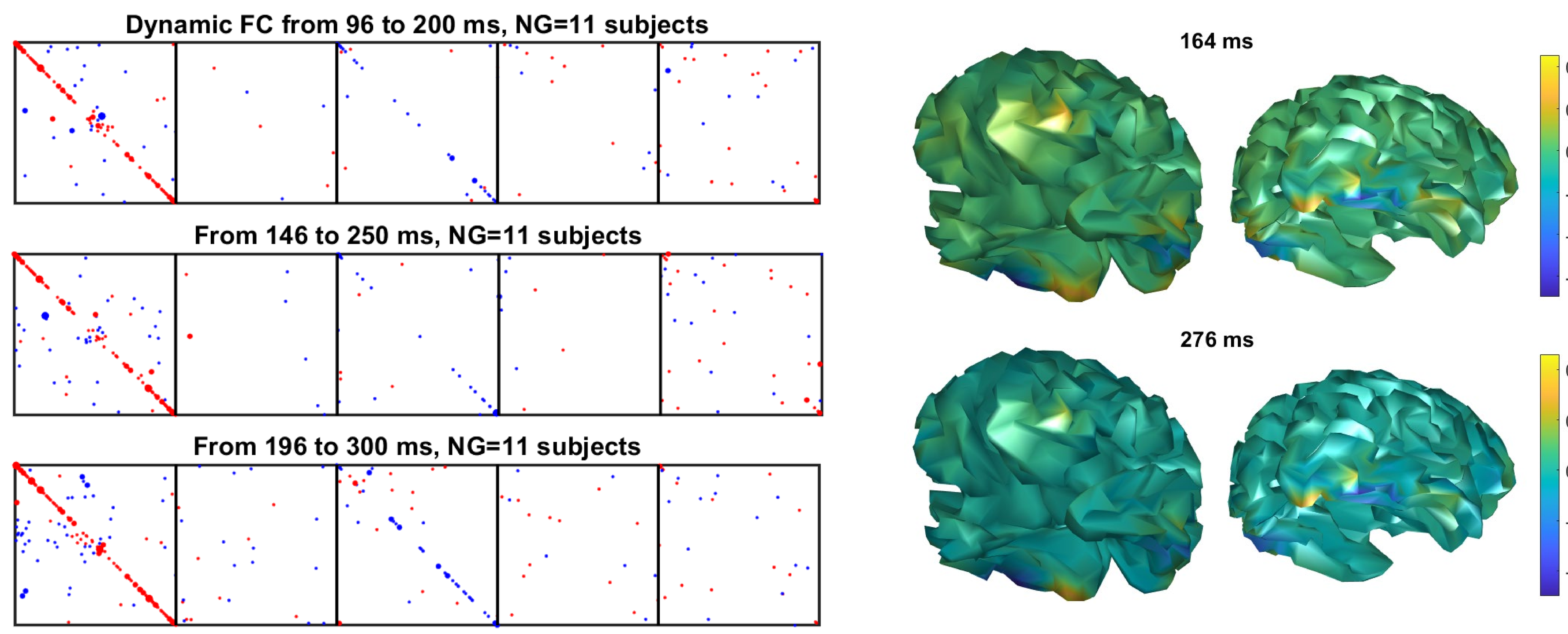
A-B) Brain source mapping. **C)** Estimation of sources time series. **D-F)** True and estimated FC maps.

Validation with simulated and real (population) EEG data

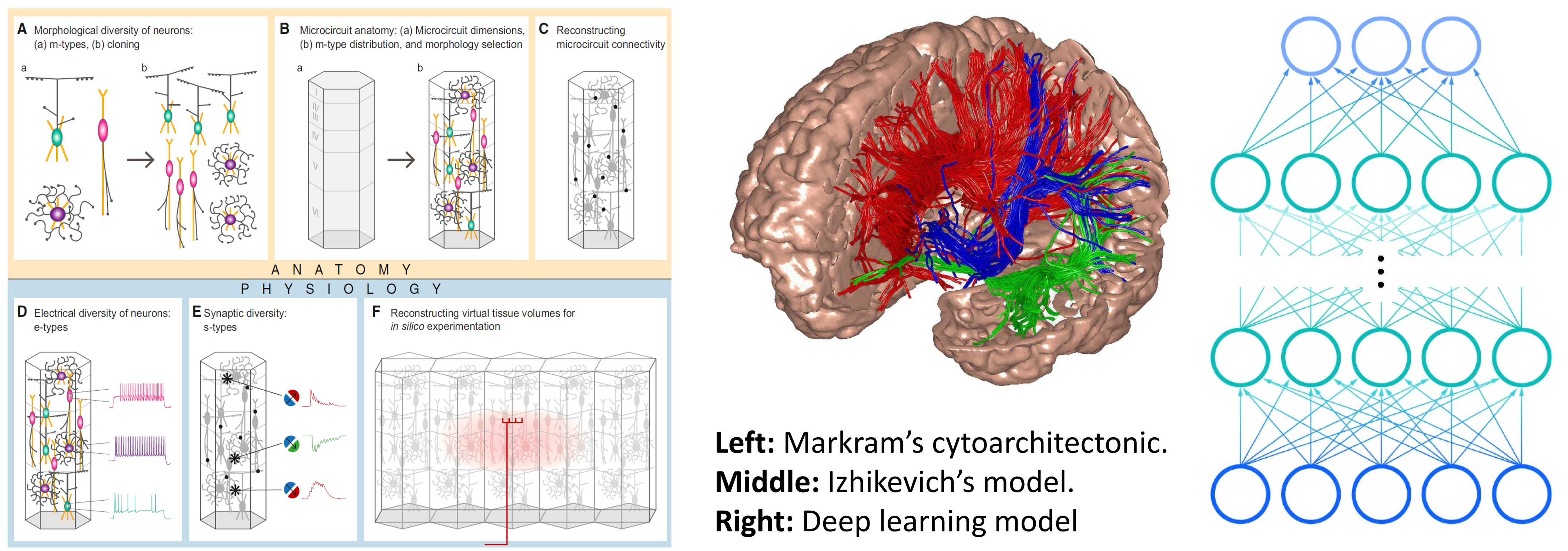
1. We simulate a population of 13 individuals with known "average" FC weights:



2. Analysis of the Wakeman and Henson's MEG/EEG dataset:



What's next? AI/Brain-inspired simulations



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

A feasible brain model must combine "practical" realism with "usefulness" to solve tasks while proposing the brain architecture (known regional networks and functions) as framework to develop learning models.

References:

Markram, Henry, et al. "Reconstruction and simulation of neocortical microcircuitry." Cell 163.2 (2015): 456-492.

Izhikevich, Eugene M., and Gerald M. Edelman. "Large-scale model of mammalian thalamocortical systems." Proceedings of the national academy of sciences 105.9 (2008): 3593-3598.

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