CYCLE

functional to structural to functional imaging: a feedbaCked strategY for intraCraniaL widEband assessments

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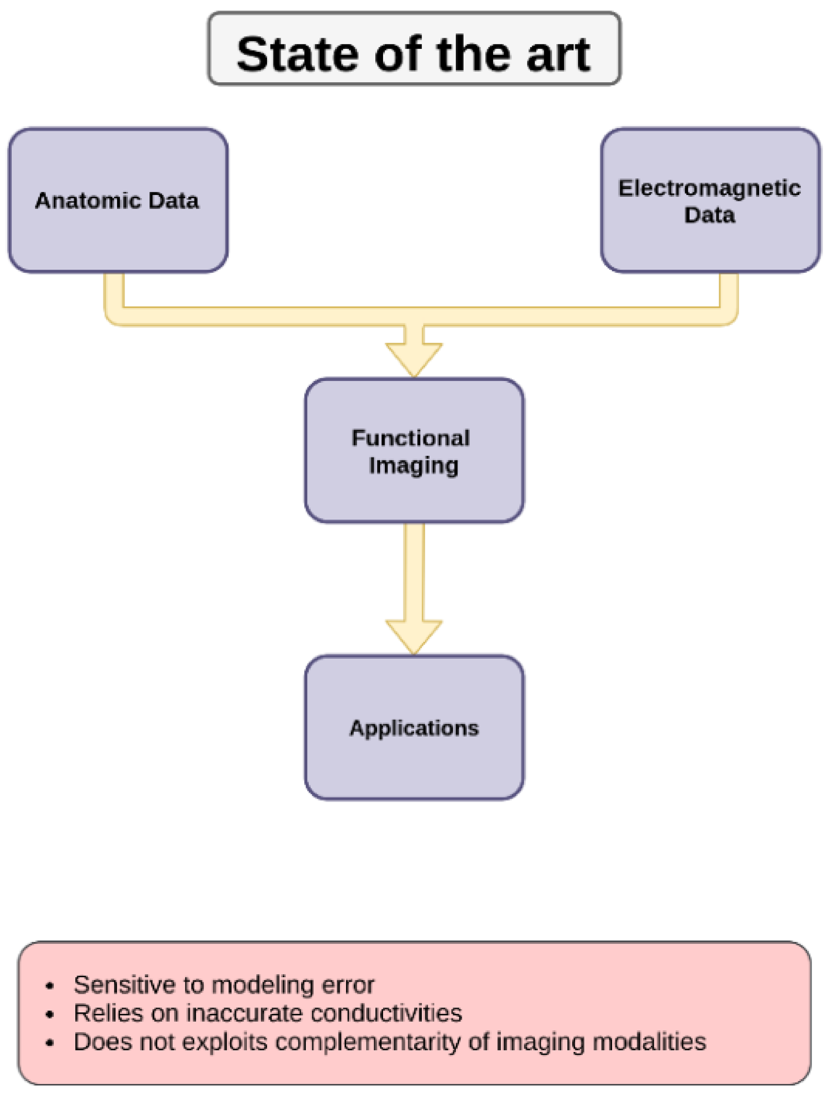
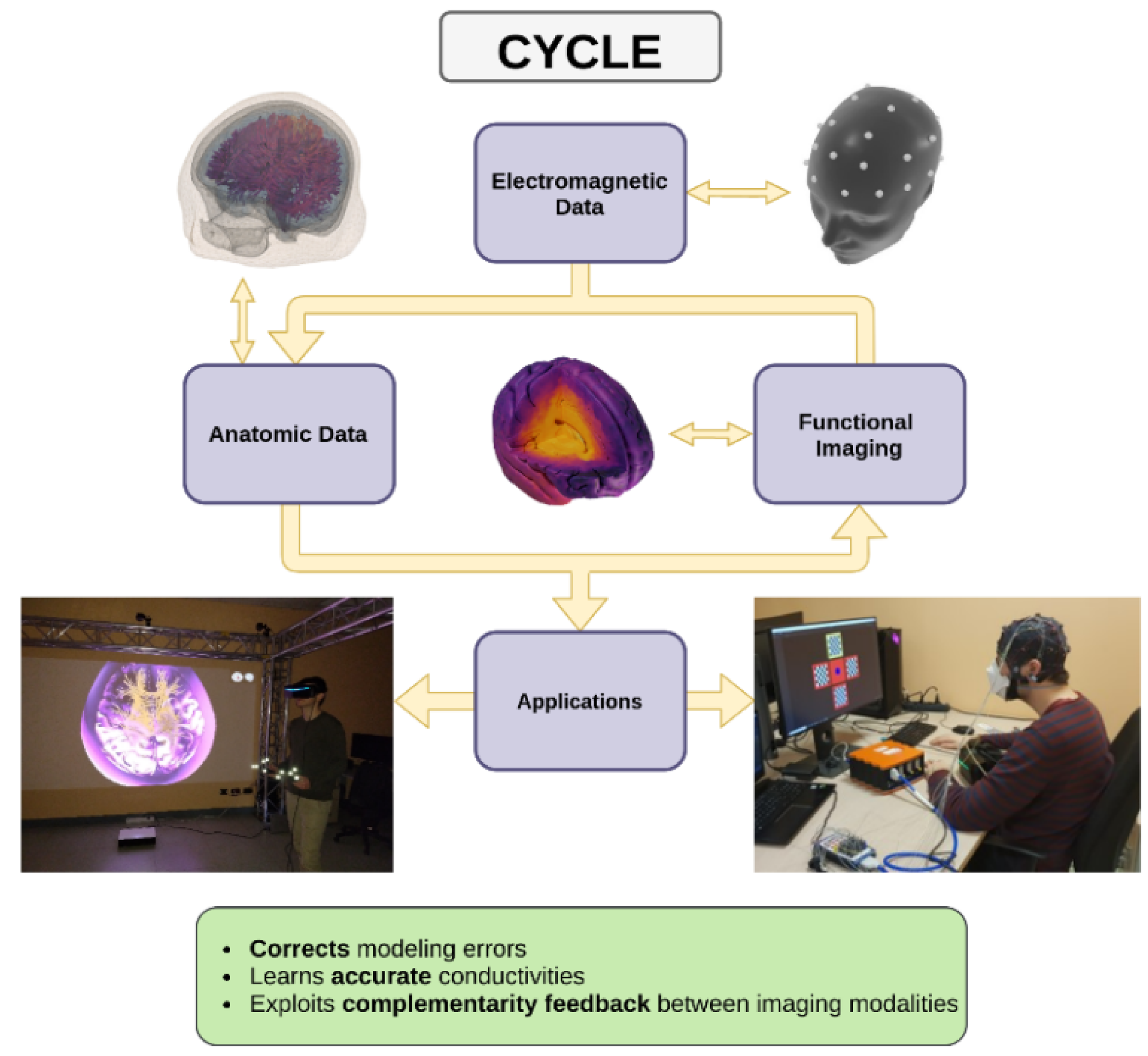
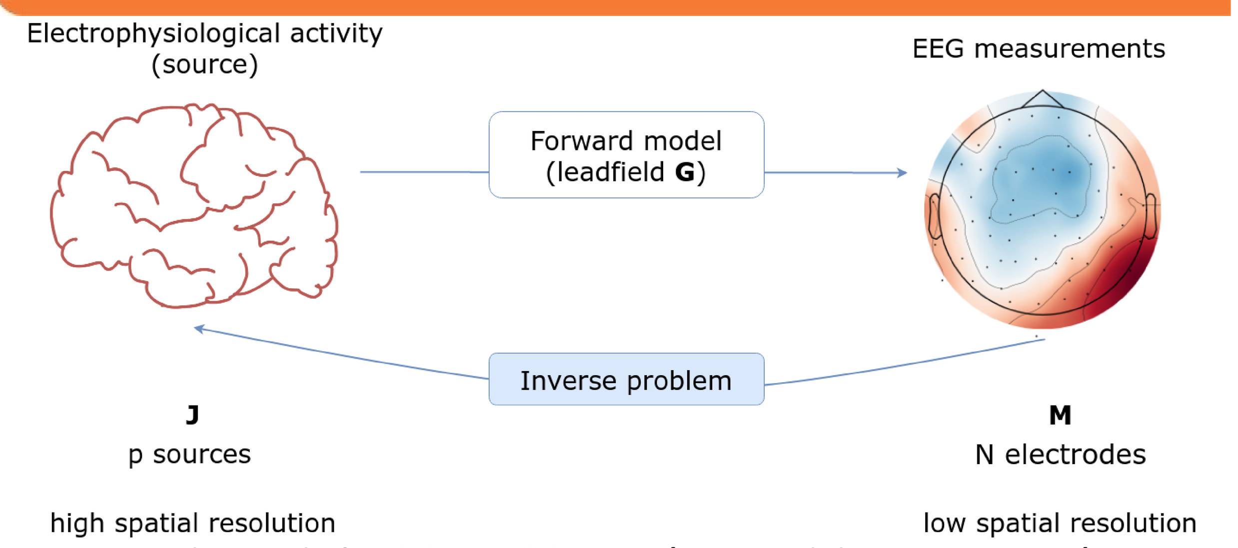
General Description





Inverse Problem in EEG



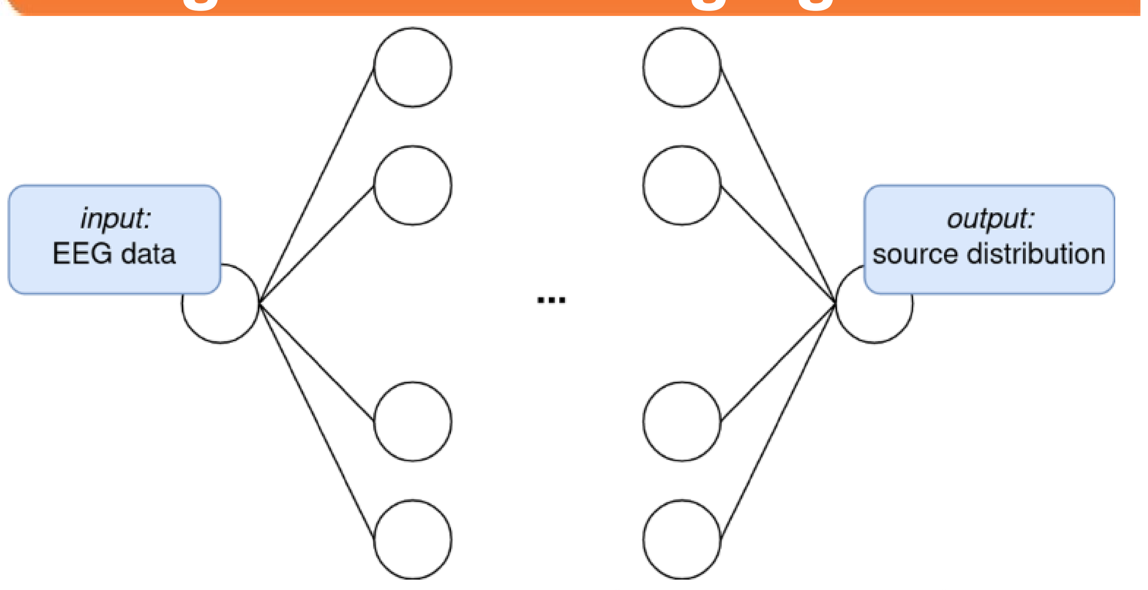
Forward model : $M = GJ + \varepsilon$ (ε = additive noise)

- $p \gg N$: G non-invertible
- Volume mixing/conduction

Ill-posed inverse problem: **add prior** on J to solve.

$$\hat{J} = \underset{J}{argmin} \{ \underbrace{||M - GJ||_F}_{\text{Data fit term}} + \underbrace{\lambda R(J)}_{\text{Regularization term}} \}$$

Deep Learning for Electrophy-siologic Source Imaging



Network parameters (e.g MSE loss):

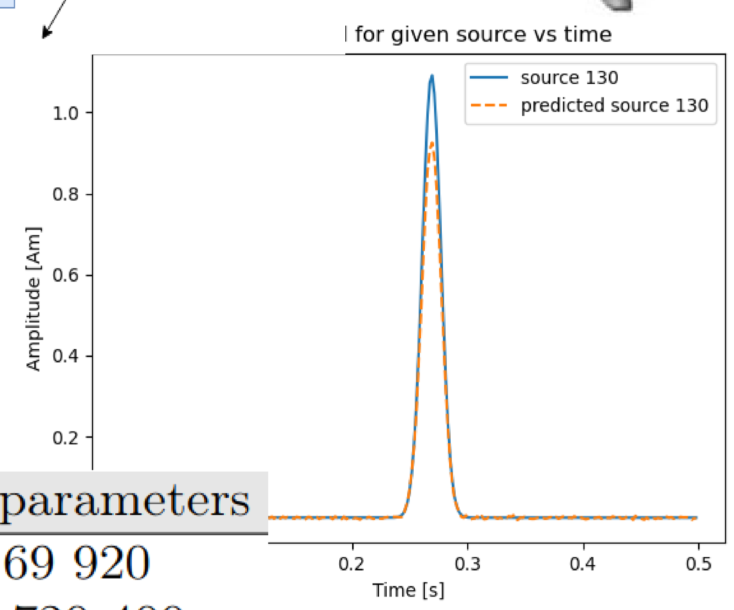
$$\hat{\theta} = \underset{\theta}{argmin} \left\{ \sum_{j=1}^{p} \sum_{k=1}^{T} (J_{j,k} - \hat{J}_{j,k})^2 \right\}$$

1d-CNN for ESI

Input and output as **multivariate time series**

Challenges:

- Accuracy drops when source space dimension increases
- Number of parameters increases with source space dimension



Head Model	Spatial Pattern	Temporal Pattern
3 layers 61 electrodes 2 source spaces: - 132 sources - 1284 sources	1 active source **Random parameters:** source position, latency, width, amplitude	SEREEGA's ERP like activation

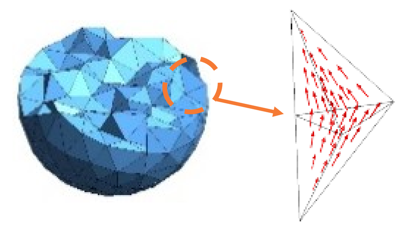
p	accuracy	nb. parameters
132	100%	69 920
1284	82.4%	5 720 400

New High-Resolution and Full Wave Forward Models

Electric Flux Volume Integral Equation for Modeling Anisotropic and Inhomogeneous objects

$$\frac{D(r)}{\epsilon(r)} - \left(\mathcal{L}_\kappa^\Omega D\right)(r) = E_i(r)$$

Discretization



$$Z\alpha = (G_\epsilon + Z_\Phi + Z_A)\,\alpha = v$$

Ill conditioned Gram matrix
→ **Low-Frequency (LF)** breakdown
→ **High-Contrast (HC)** breakdown

Regularization of HC and LF Breakdowns with Generalized Volume Quasi-Helmholtz Projectors [1]

New Projectors

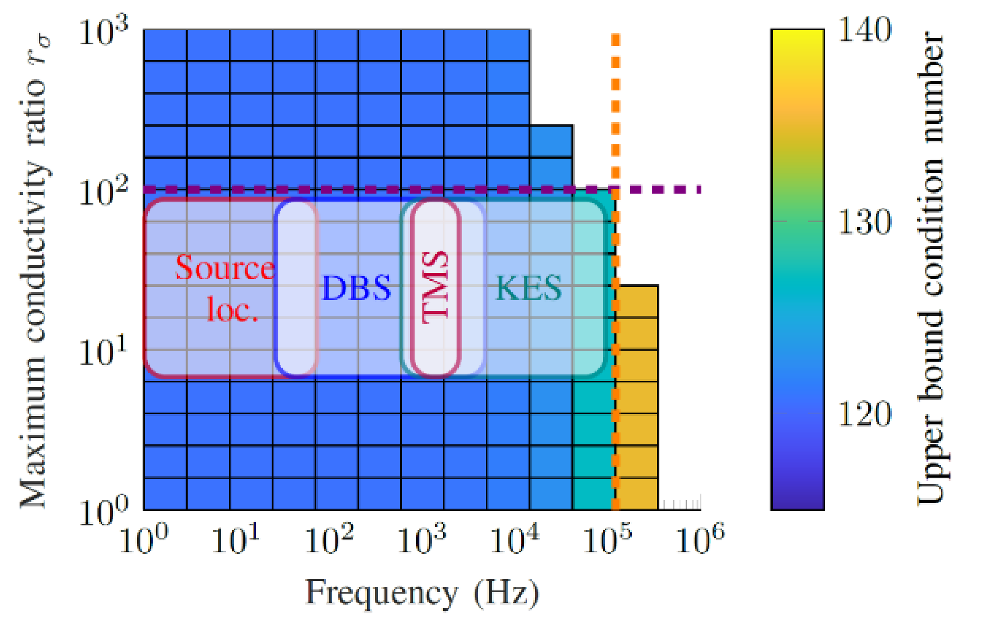
$$P^{\Sigma}_{G_\epsilon} = G_\epsilon^{-1}\Sigma\left(\Sigma^T G_\epsilon^{-1}\Sigma\right)^+ \Sigma^T$$

$$P^{\Lambda}_{G_\epsilon} = I - P^{\Sigma}_{G_\epsilon} = \Lambda\left(\Lambda^T G_\epsilon \Lambda\right)^+ \Lambda^T G_\epsilon$$

Left Preconditioner

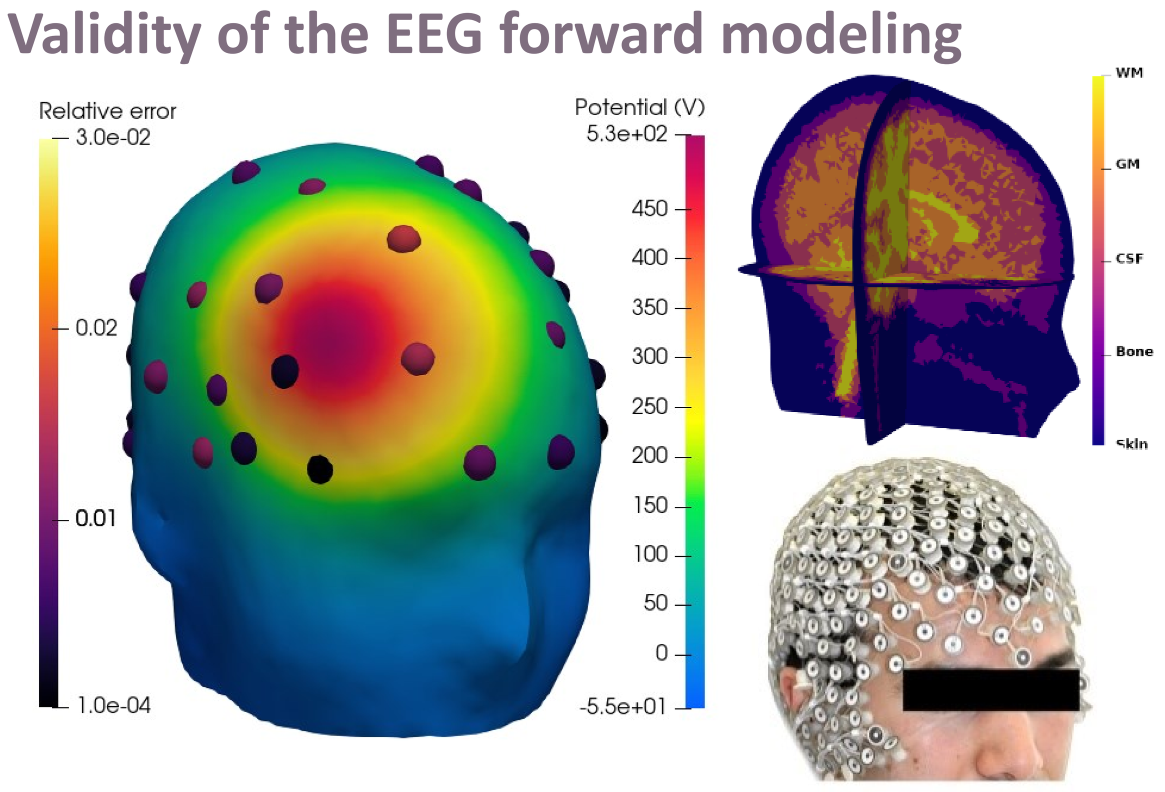
$$L_{G_\epsilon} = P^{\Lambda}_{G_\epsilon} G_\epsilon^{-1} + P^{\Sigma}_{G_\epsilon} G^{-1}$$

Range of operation of the formulation



DBS: Deep brain stimulation, TMS: Transcranial Magnetic stimulation, KES: Kilohertz electrical stimulation

Validity of the EEG forward modeling



Ongoing Work and Next Steps

- **Software acceleration** of **the forward solver** using a parallelized implementation of the adaptive integral method
- **Complexify simulations** (source extension, multiple sources, other waveforms, noise)
- Work on IP's **data representation** and **architecture choice**
- Integrate BCI **feedbacked strategy**
- **Experimental Validation**

Published Results

[1] C. Henry, A. Merlini, L. Rahmouni, and F. P. Andriulli. "On a Low-Frequency and Contrast Stabilized Full-Wave Volume Integral Equation Solver for Lossy Media". In: IEEE Transactions on Antennas and Propagation (2022)

[2] C. Henry, A. Merlini, and F. P. Andriulli. "Oblique Quasi-Helmholtz Projectors for Electric Flux Volume Integral Equations: Differential Forms and Conditioning Analysis". In: 2022 IEEE APS URSI (July 2022)

[3] D. Consoli, C. Henry, A. Dély, L. Rahmouni, J. E. Ortiz Guzman, T. L. Chhim, S. B. Adrian, A. Merlini, and F. P. Andriulli. "On the Fast Direct Solution of a Preconditioned Electromagnetic Integral Equation". In: 2022 IEEE ICEAA (Sept. 2022)