Source localization from multichannel EEG/MEG: mathematics or neuroinformatics?

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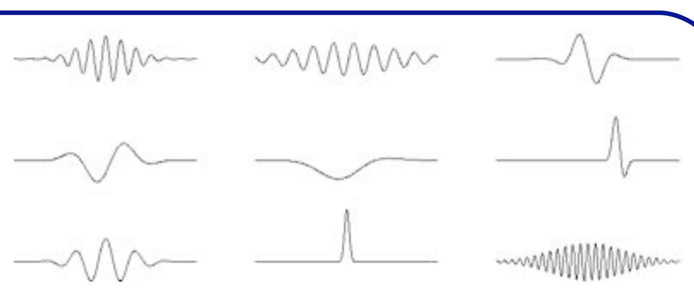
Spatial sources of activity observed in multichannel EEG/MEG recordings can be assessed only via the EEG/MEG inverse problem, which does not have a unique solution: there is an inf nite number of sources conf gurations, which give the same potentials or f elds distribution measured on the skull surface. Choosing a solution requires extra assumptions of mathematical, neuroanatomical and neurophysiological nature, and we have no clear-cut criteria for their choice. The problem is neither purely algorithmic, nor engineering or neurophysiological. We prove that it is a neuroinformatics problem, and sketch the way towards a coherent progress via (1) novel preprocessing algorithms, and (2) sharing datasets.

We start by creating large and redundant dictionary *D* of candidate waveforms – usually Gabor functions:



$$g_\gamma(t) = e^{-\pi\left(\frac{t-u}{s}\right)^2}\cos\left(\omega(t-u)+\phi\right)$$

In the f rst step of the **matching pursuit** (MP), the waveform which best matches the signal *x* is chosen from dictionary *D*. In each of the consecutive steps, next waveform is matched to the residual left after subtracting results of previous iterations:

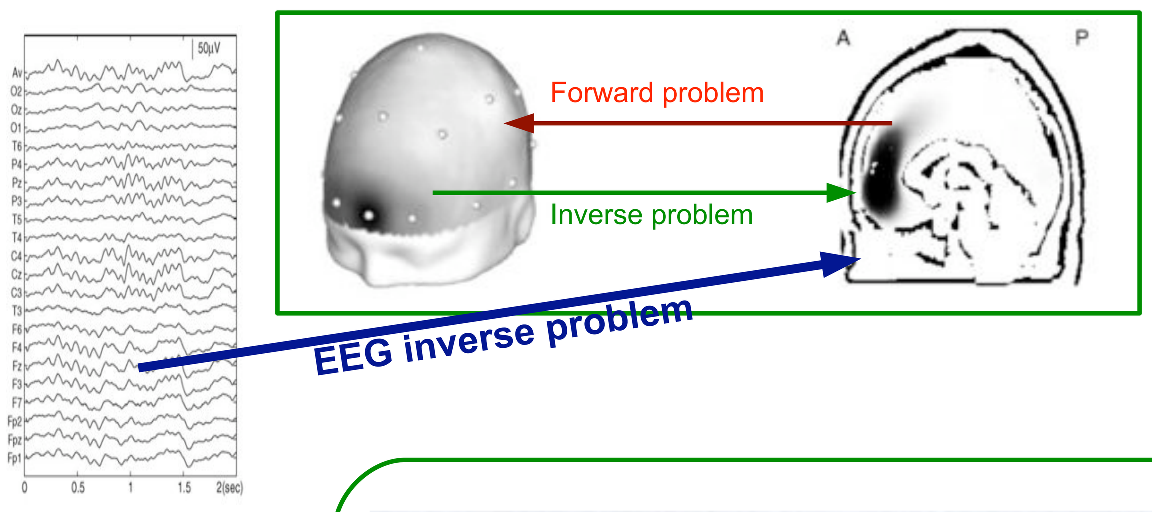
$$\begin{cases} R^0 f = f \\ R^n f = \langle R^n f, g_{\gamma_n}\rangle g_{\gamma_n} + R^{n+1} f \\ g_{\gamma_n} = \arg\max_{g_{\gamma_i}\in D} |\langle R^n f, g_{\gamma_i}\rangle| \end{cases}$$

The most straightforward multichannel extension of the MP can be achieved by allowing different amplitudes across channels and maximizing the sum of energies in channels

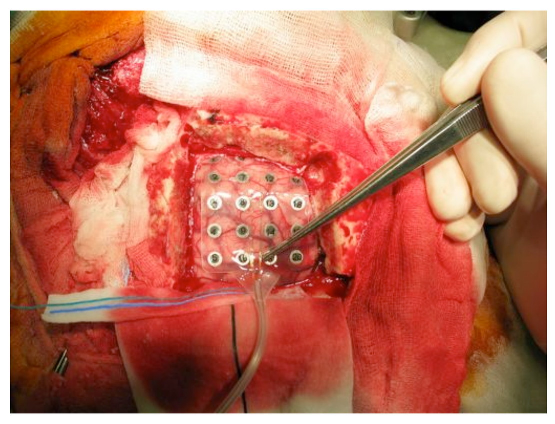
$$\begin{cases} R^0 \mathbf{x} = \mathbf{x} \\ R^n \mathbf{x}^i = \langle R^n \mathbf{x}^i, g_{\gamma_n}\rangle g_{\gamma_n} + R^{n+1}\mathbf{x}^i \\ g_{\gamma_n} = \arg\max_{g_\gamma\in D} \sum_{i=1}^{N_c} |\langle R^n \mathbf{x}^i, g_\gamma\rangle|^2 \end{cases}$$

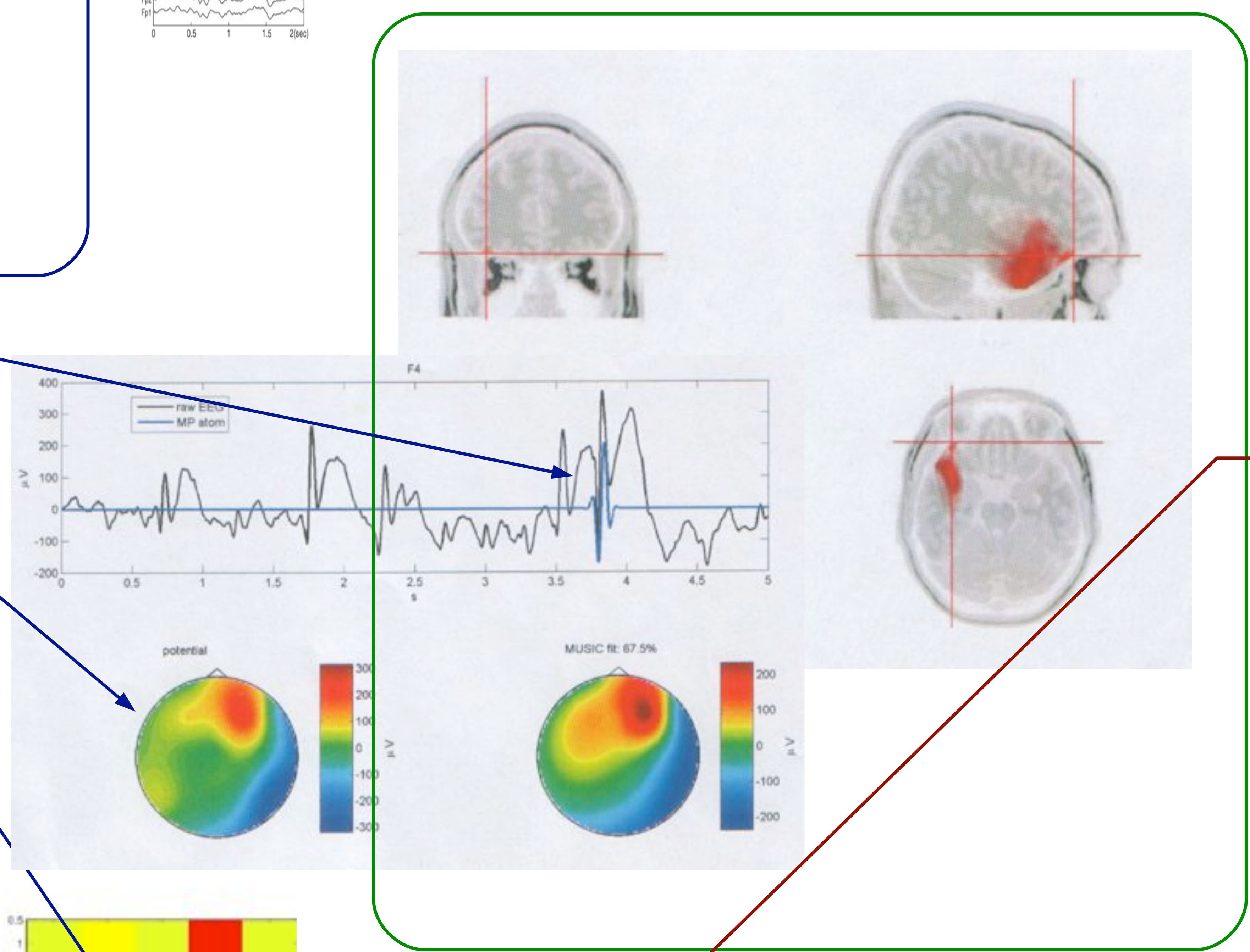
Results are given in terms of functions, selected in consecutive iterations, and their weights across the channels.

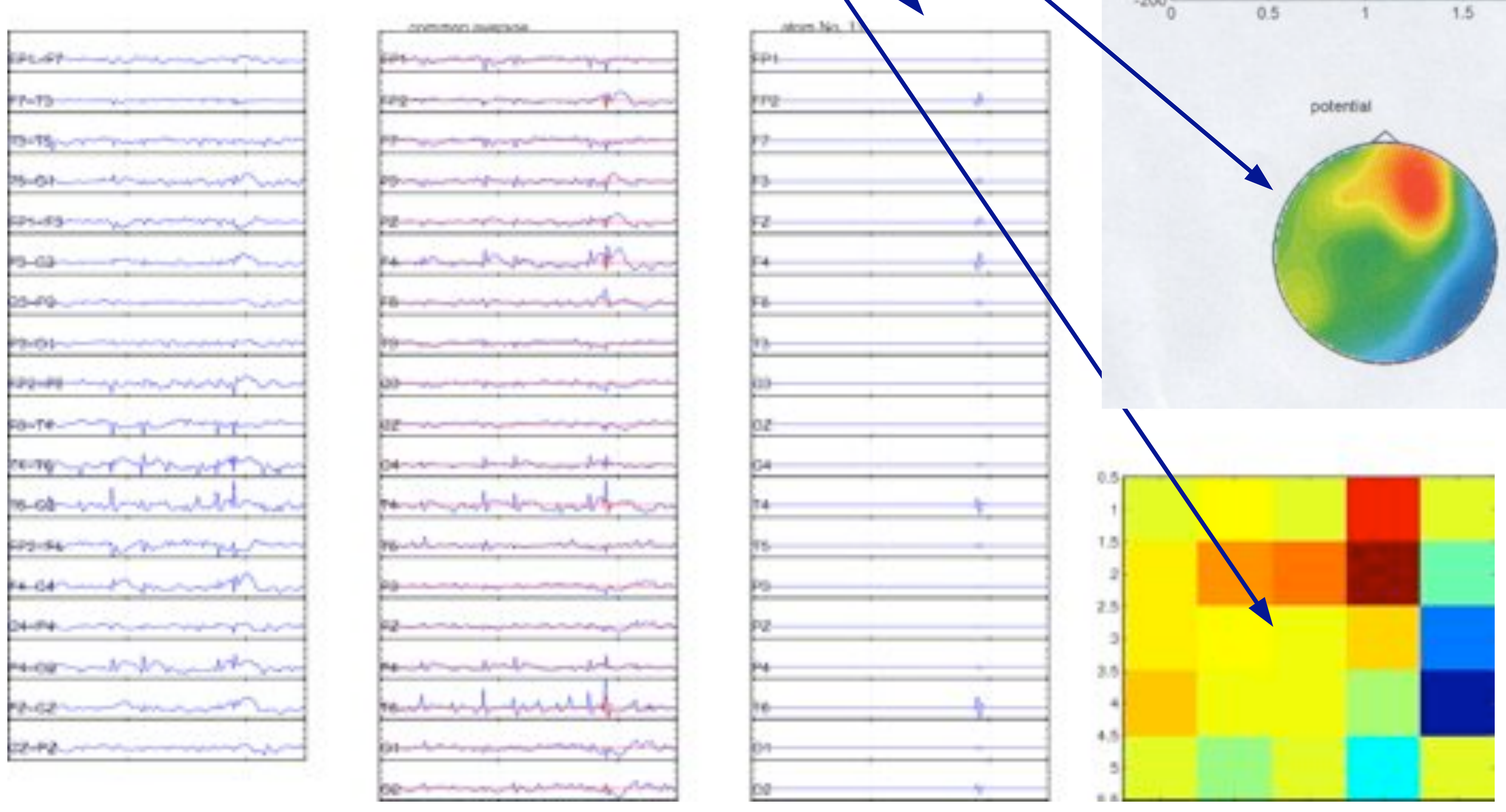
Contrary to the common belief , EEG/MEG inverse problem does not lead from the scalp distribution of amplitudes to the spatial localization of sources (green box on the picture), but starts with the recorded time series (red arrow). Mathematical properties of inverse solutions (IS) make them exceedingly sensitive to the input noise: small changes in the input data (sensors noise) may result in large changes of the computed source localizations. We proposed to reduce the input noise by selective and sensitive extraction of relevant activities from the EEG/MEG data via multichannel matching pursuit algorithm. It yielded improvement in localization about orders of magnitude, compared to the traditional preprocessing based upon spectral integrals.



Source localization has hard implications in treatment of certain types of epilepsy, where removal of a proper part of the brain tissue is the only hope for patients improvement. These cases provide also unique possibility of verif cation of the accuracy of the Inverse Solutions computed from the pre-operational surface EEG, owing to the availability of intracranial recordings from the same patients, aimed at foci localization and post-operational assessment. At EEG.pl, we are creating a database of benchmark datasets selected from such cases. Together with the freely available software (e.g. multichannel matching pursuit), they allow for implementing the principles of Reproducible Research, which is the only way towards a coherent progress in this f eld.

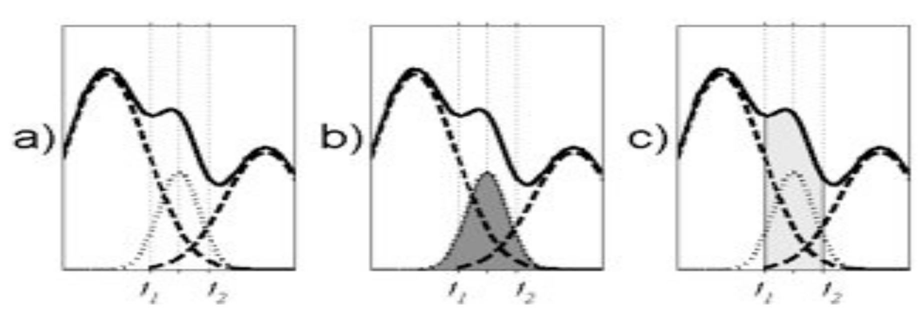






(a) (b) (c) (d)

Epileptologist ohooses epochs of 10-20 interictal EEG recordings, containing clinically relevant epileptic discharges (a). After converting to common average montage (b) we perform multichannel matching pursuit decomposition. For the Gabor atoms corresponding to the epileptogenic activity (c) we get both time courses (constant across the channels, differing only in amplitude) and distributions across electrodes (d). These distributions can serve as an input to any EEG Inverse Solution algorithm – hereby MUSIC, **courtesy of Guido Nolte and Stefan Haufe from Fraunhofer FIRST, Berlin**. Intra-operational ECoG, MRI scans and clinical data provide a posteriori verif cation of the assessed spatial location of the epileptogenic zone.

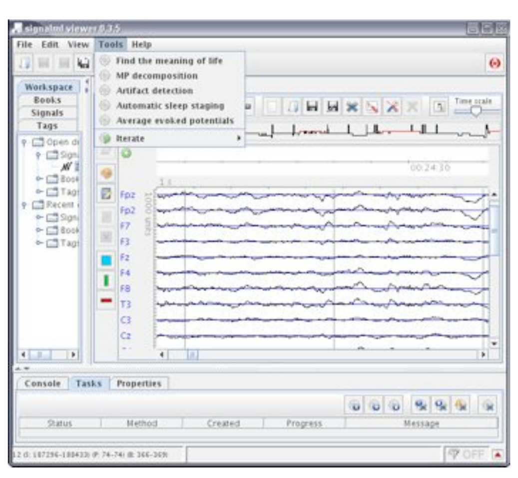


Possible improvement resulting from the MMP preprocessing stems from the uncertainty principle in signal analysis (left): (a) hypothetical spectrum resulting from presence of three different frequencies (b) actual energy estimated by MP (in case the oscillations were correctly modeled by Gabor functions) (c) energy of the structure estimated by spectral integral within predef ned band.

References:

uni.durka.info

signalml.org



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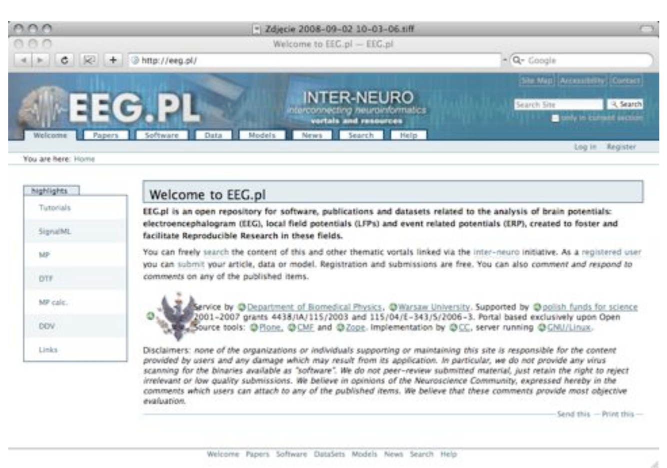

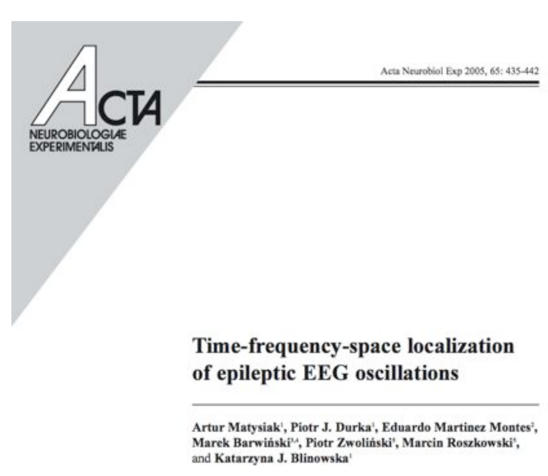

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