Inverse Current Source Density in three dimensions

Szymon Łęski[1], Daniel K. Wójcik[2,3], Joanna Tereszczuk[4], Daniel A. Świejkowski[2], Ewa Kublik[2], Andrzej Wróbel[2,3]

Our goal is to develop a method for studying the activity of geometrically complex brain structures

Typical sensory stimulation evokes activity of many different brain structures. Therefore, to get hold of the complete response it is necessary to record the local field potentials (LFPs) at many sites simultaneously.

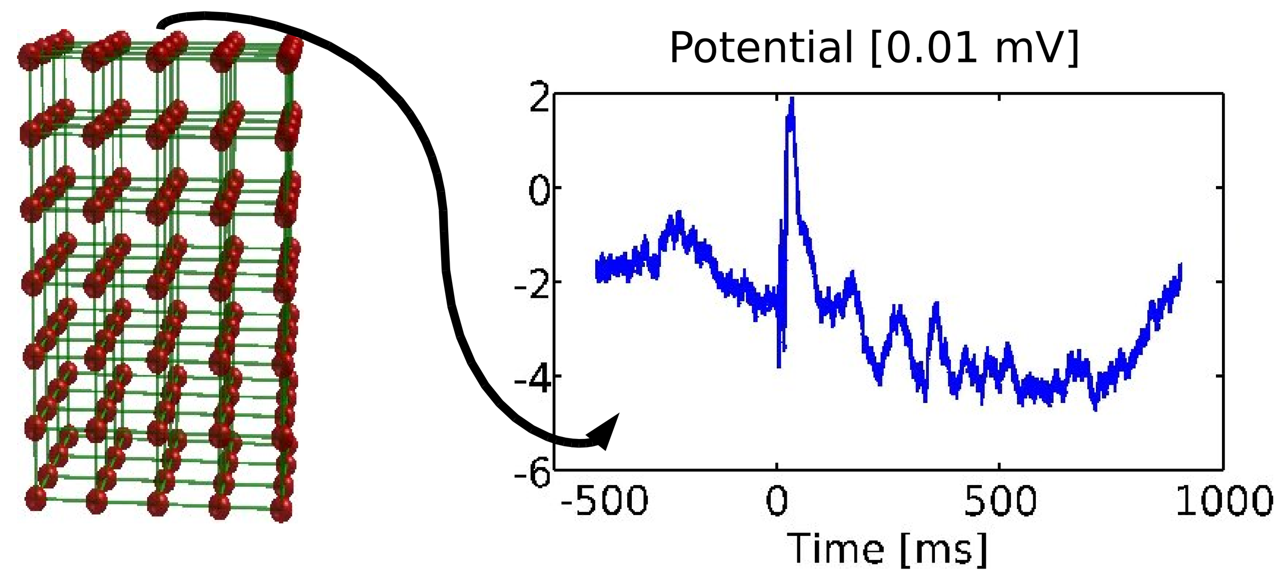
The long range nature of electric forces implies that every region of electric activity (concerted trans-membrane currents) is visible in the recordings at many sites. This complicates the analysis of electrophysiological data.

To study information processing in thalamo-cortical loops, oscillations, synchronization etc., it is often of advantage to analyze the distribution of the current sources instead of the measured LFPs. These sources are often well localized in specific brain structures. Inference of current sources from LFPs is known as the Current Source Density (CSD) method.

Experimental model: deep structures of the rat forebrain

We studied sub-cortical parts of the rat somatosensory system. We recorded the potentials evoked by the deflection of a bunch of whiskers. The recording area included vibrissa-responsive thalamic nuclei of different kinds. The spatial organization of the studied region is much more complicated than the organisation of the somatosensory cortex: there are no columns and the structure is not laminar.

We recorded the evoked potentials on a three-dimensional grid (4 x 5 x 7)



How to evaluate currents from the recorded potentials?

The potentials ϕ and the current sources C are related *via* the Poisson equation:

$$\sigma \Delta \phi = -C$$

In principle one could use a numerical second derivative to estimate C. However, one would then lose all the boundary points. In one-dimensional situation one loses only 2 points, but in our case we would lose 110 out of 140 measurements!

Therefore we needed another method. We adapted the one-dimensional inverse CSD (iCSD) method proposed by Pettersen et al. (2006) to the three-dimensional situation.

Suppose we know the distribution C of the current sources. It is a simple matter to evaluate the potentials measured at any point in space.

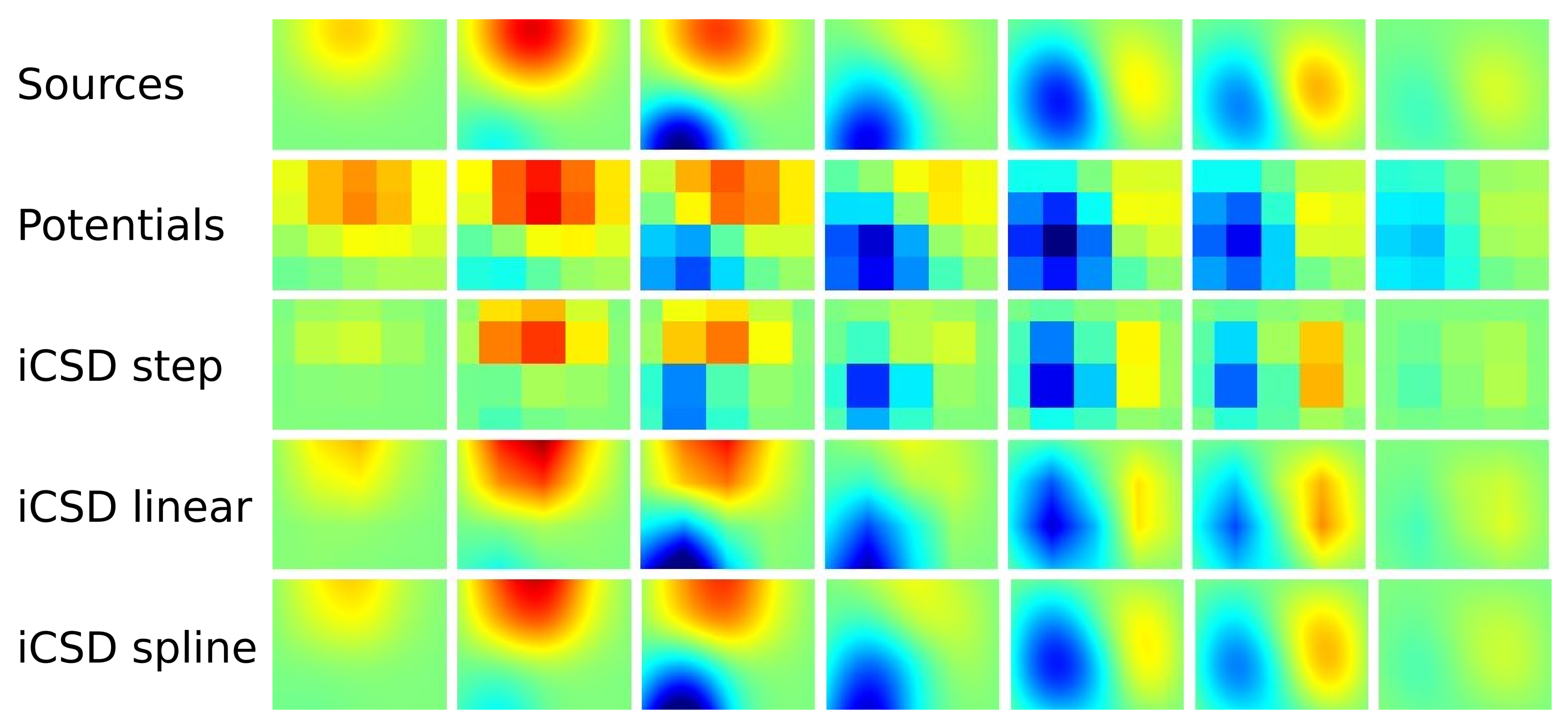
Suppose further that the current source distribution is parameterized with N (=number of grid points) parameters, for example with the values of C at the grid points. We get a relation

$$\phi \text{ at grid points} = \mathrm{F}[\text{N parameters of CSD}]$$

and the operator F can usually be inverted. This leads to the values of N parameters expressed in terms of measured potentials:

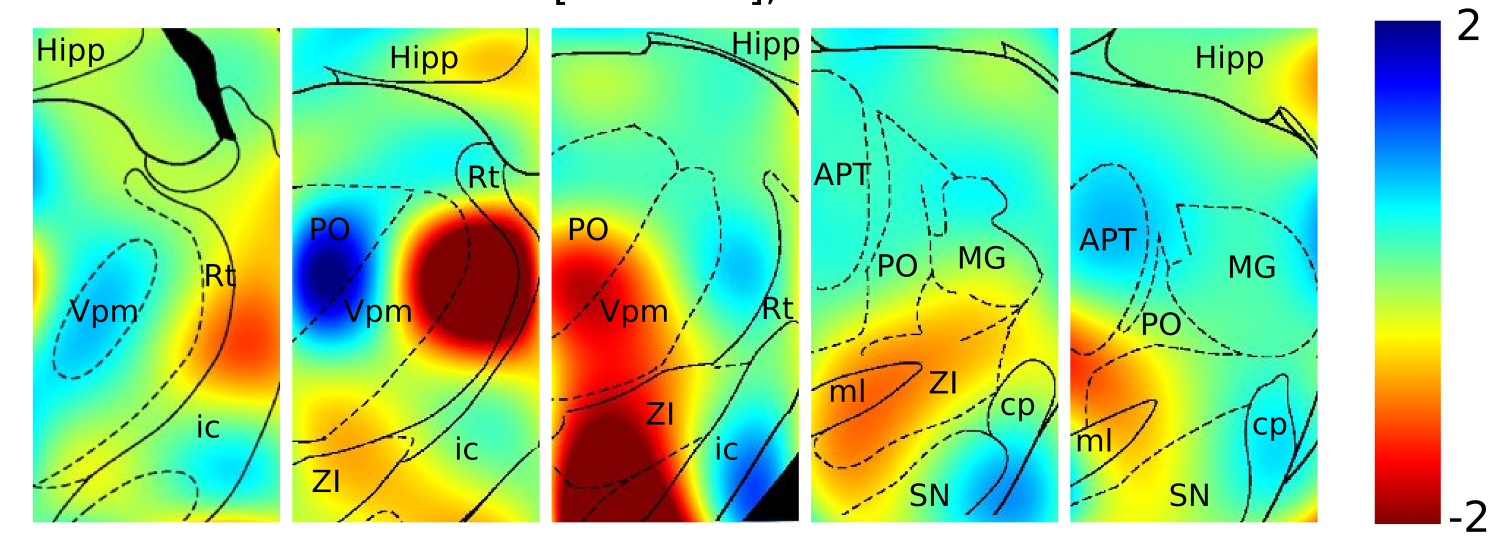
$$\text{N parameters of CSD} = \mathrm{F}^{-1}[\phi \text{ at grid points}]$$

Analysis of test data (comparison of different methods)

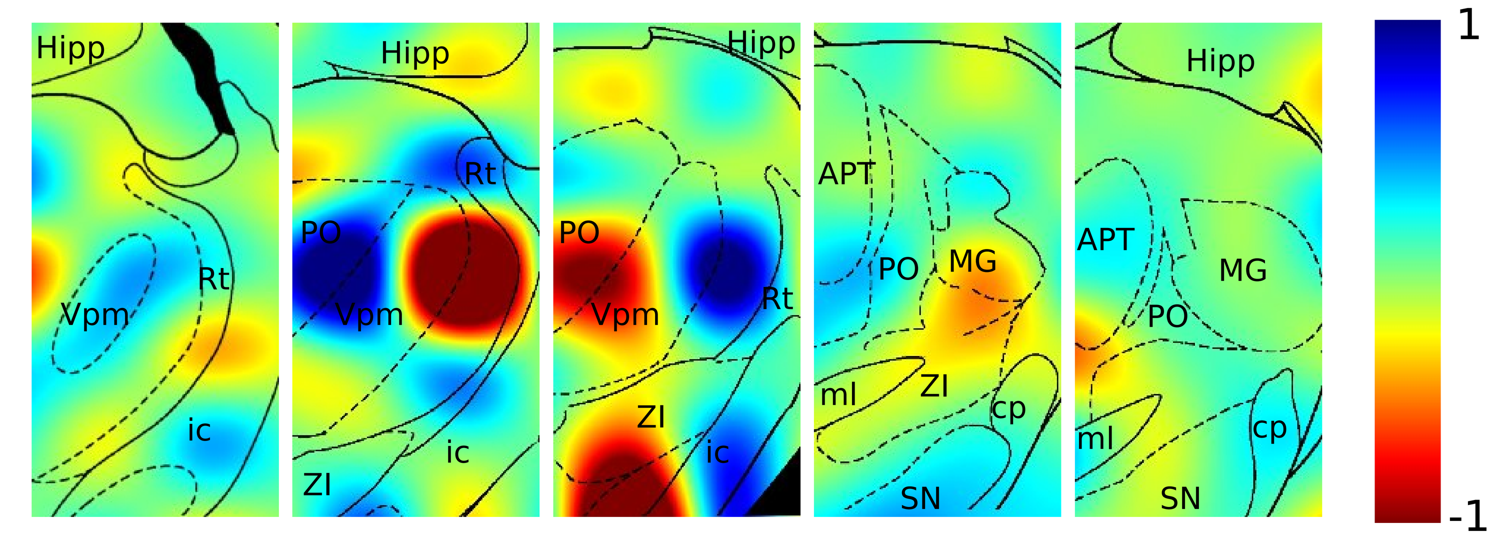


Evoked activity: potentials vs. currents

Potentials [0.01 mV], t = 3.5 ms

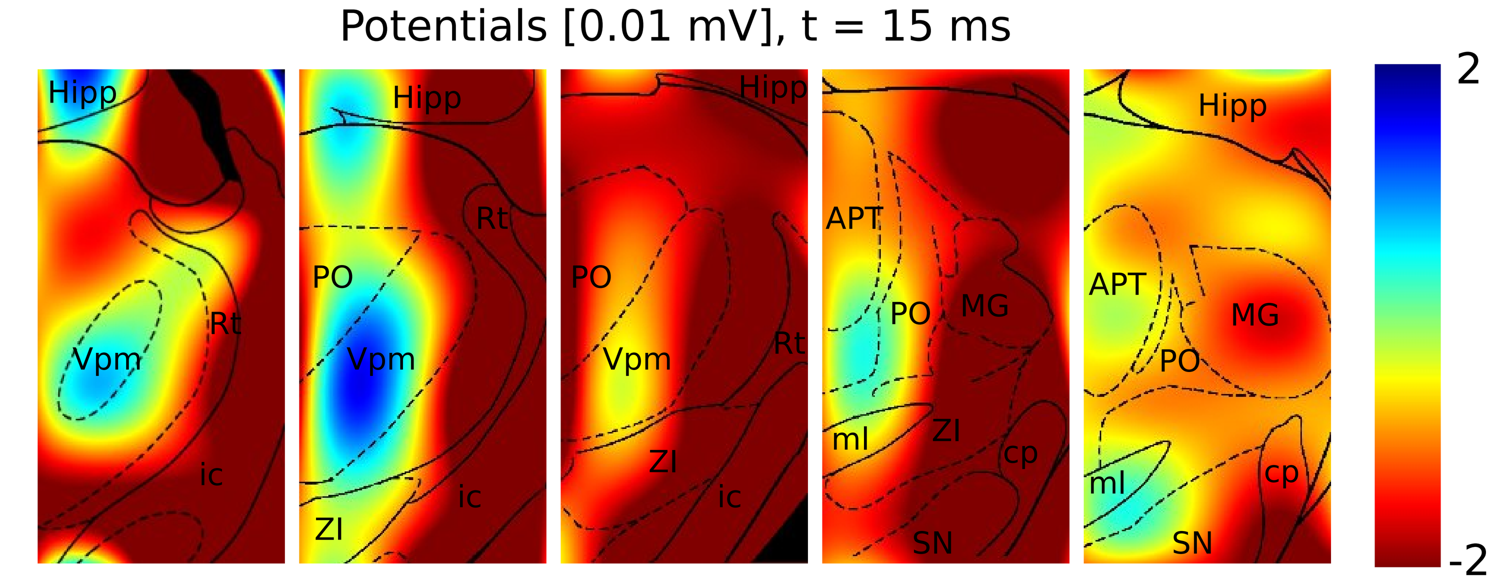


Current source density [100 nA/mm^3], t = 3.5 ms

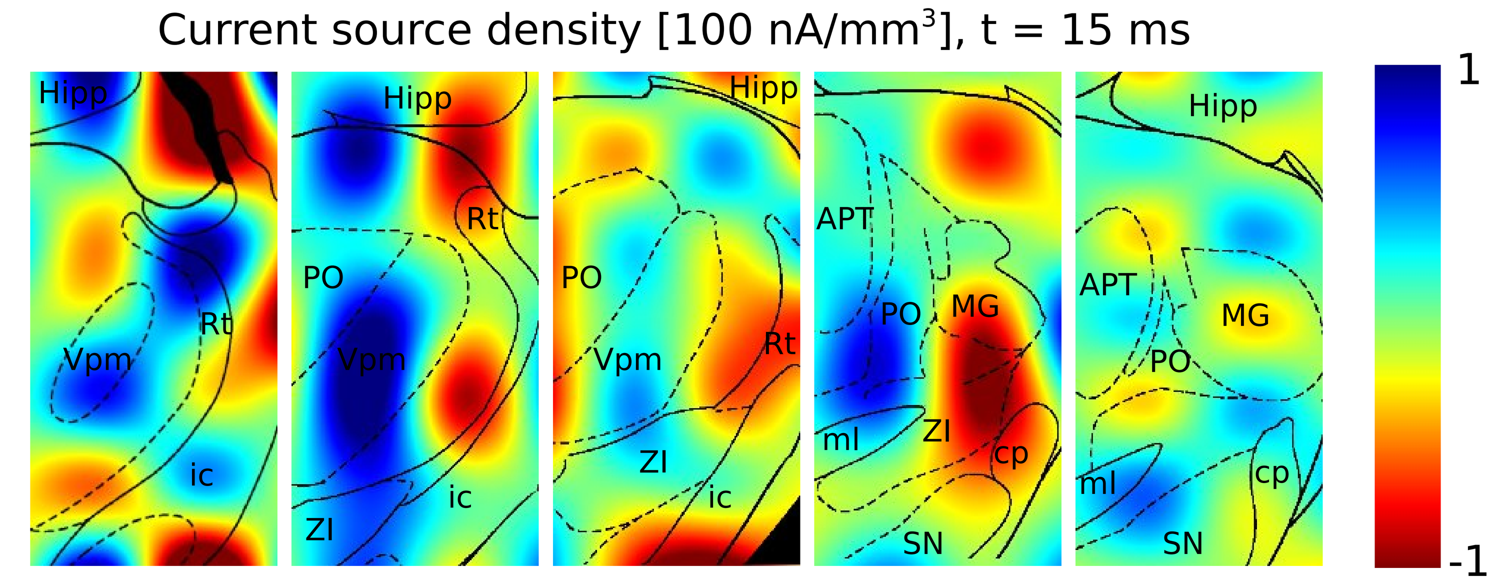


Analysis of currents:
- better spatial resolution
- better understanding of the system

Potentials [0.01 mV], t = 15 ms



Current source density [100 nA/mm^3], t = 15 ms



Affiliations
1. Center for Theoretical Physics, Polish Academy of Sciences
2. Nencki Institute of Experimental Biology, Polish Academy of Sciences
3. Warsaw School of Social Psychology
4. Warsaw University of Technology

Acknowledgements
Partially financed from the Polish Ministry of Science and Higher Education research grants N401 146 31/3239 and 2P04C 046 27.

References
Nicholson C, Freeman JA (1975) Theory of current source-density analysis and determination of conductivity tensor for anuran cerebellum, J Neurophysiol 38:356-368
Nunez PL (1981) Electric Fields of the Brain, Oxford Univeristy Press
Paxinos G, Watson C (1996) The Rat Brain in Stereotaxic Coordinates, Compact Third Edition, Academic Press
Pettersen KH, Devor A, Ulbert I, Dale AM, Einevoll GT (2006) Current-source density estimation based on inversion of electrostatic forward solution: effects of finite extent of neuronal activity and conductivity discontinuities, J Neurosci Methods 154:116-133

Anatomical abbreviations:

APT	anterior pretectal nucleus
Hipp	hippocampus
MG	medial geniculate nucleus
PO	posterior thalamic nuclear group
SN	substantia nigra
ZI	zona incerta
cp	cerebral peduncle
ic	internal capsule
ml	medial lemniscus
Rt	reticular thalamic nucleus
Vpm	ventral posteromedial thalamic nucleus