product of distributed dipole moments and their respective lead field matrix. In a similar way, the measured field can be represented as a product of a multipole lead field matrix and the coefficients of a multipole expansion. In both cases, the lead field matrix does not depend on the data, but rather only on sensor and field generator (i.e. dipoles or multipole expansion point) positions and can be calculated a priori.

These equations can be used to recalculate the data to a virtual multichannel system or to construct a transfer matrix that recalculates data from one real multichannel system to another one just by a single matrix multiplication. Beside of regularization effects, the transfer matrix is independent from the applied field representation method.

We demonstrate results of recalculations of real MCG data between the different multichannel systems in Berlin, Bochum and Jena.


7-44: A Unified Bayesian Framework for MEG/EEG Source Imaging
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The ill-posed nature of the MEG/EEG source localization problem requires the incorporation of prior assumptions when choosing an appropriate solution out of an infinite set of candidates. Bayesian approaches are useful in this capacity because they allow these assumptions to be explicitly quantified using postulated prior distributions. However, the selection of these priors, as well as the estimation and inference procedures that are subsequently used for localization, have led to a daunting array of algorithms with seemingly very different properties and assumptions. From the vantage point of a simple Gaussian scale mixture model with flexible covariance components, we analyze and extend several broad categories of Bayesian methodology directly applicable to source localization including empirical Bayesian approaches, standard MAP estimation, and variational Bayesian (VB) approximations. Theoretical properties related to convergence, global and local minima, and localization bias are rigorously analyzed and principled algorithms are derived that improve upon existing methods in speed and robustness. We also detail explicit connections between established algorithms and outline natural extensions for handling unknown dipole orientations, extended source configurations, correlated sources, temporal smoothness, and model selection. Specific imaging methods elucidated include the weighted minimum L2 norm, minimum current estimation (MCE), FOCUSS, sLORETA, restricted maximum likelihood (ReML), beamforming, variational Bayes, the Laplace approximation, automatic relevance determination (ARD), and VESTAL, as well as many others. All of these methods can be formulated as particular cases of covariance component estimation using different concave regularization terms and optimization rules, making general theoretical analyses and algorithmic extensions/improvements particularly relevant. Wherever possible, theoretical results are derived in a general setting and therefore propagate down to specific cases.

7-45: The use of surrogate brains to test MEG source reconstruction
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Recent work has shown that the validity of an MEG volumetric image of neuronal activity can be tested by comparing it against the grey-matter anatomy [1]. This approach used rotations of a spherical region of cortex to show that MEG beamformer images contained more information on the unrotated anatomy than a set of rotated surrogates. The main problem with this approach is that it can only test a spherical region of the source space. We introduce a new method for creating surrogate cortical surfaces using a spherical harmonic decomposition of the surface [2]. Using this technique it is possible to reconstruct the cortex at progressively finer levels of spatial scale; and also to deform certain spatial scales whilst preserving the others (for example, maintaining the overall shape of the brain but deforming the gyral anatomy). Most importantly, the surrogates occupy the whole brain volume and could potentially be used to test not only the validity of the assumptions behind any inversion algorithm but also its spatial resolution.[1] Barnes GR, Furlong PL, Singh KD, Hillebrand A.A. verifiable solution to the MEG inverse problem. Neuroimage. 2006 Jun;31(2):623-6. Epub 2006 Feb 9. [2] Chung MK, Dalton KM, Shen L, Evans AC, Davidson RJ. Weighted fourier series representation and its application to quantifying the amount of gray matter. IEEE Trans Med Imaging. 2007 Apr;26(4):566-81.
Abstract / Poster: 7 Inverse/Forward modeling and solution (9)

7-46: Evaluation metrics for distributed source solutions
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In order to fairly evaluate the performance of distributed source solutions, and compare them between different methods and sensor configurations, objective evaluation metrics are required that describe all relevant aspects of the inverse solutions. We argue that such an evaluation should include the following three major aspects: 1) Localization accuracy, i.e. a measure describing the discrepancy between estimated activation and the true source location. 2) The spatial extent of the source estimate around the true source locations. 3) The relative amplitudes of source estimates for different locations. We measured localization accuracy with both peak-to-peak and center of gravity measures. The extent of activity was measured by the area of cortex activated above a specified threshold, as well as by the "spread", which takes into account both the distance of an activated area from the true source locations and its amplitude. "Focality" measures the ratio of the amplitudes within a certain area around the true source location and the overall activity. "Amplitude Sensitivity" measures the peak activity or overall activity of source distributions for sources at different locations.

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Focality measures the ratio of the amplitudes within a certain area around the true source location and the overall activity.

Amplitude Sensitivity measures the peak activity or overall activity of source distributions for sources at different locations.

We applied these measures to point spread functions/resolution kernels obtained by L2 minimum norm estimation (MNE) on a cortical surface in a realistic boundary element model of the head. We compared different configurations of magnetometers, gradiometers and EEG sensors. The proposed measures quantify the benefit of combining information from different sensor types, and illustrate general resolution limits of the EEG/MEG inverse problem, e.g. with respect to depth resolution. The merits and limitations of these different measures are discussed.

7-47: Coherent source mapping from neuromagnetic recordings
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In functional brain studies, coherent source mapping for probing the binding mechanism of connected functional assemblies receives great attention in the past few years. Recently, oscillatory synchronization in particular frequency bands has been shown to be closely related to the communication within a neural circuit. Based on the beamforming technique, DICS (Dynamic Imaging of Coherent Source) method can map the cortical sources that are statistically coherent to a specified reference at a certain frequency band. The limitation of the DICS method is that the synchronization frequency band is considered to be stationary during the task. In this work, we propose a new method, the maximum-normalized correlation beamformer, for the mapping of the cortical oscillatory coupling. We compute the autocorrelation and cross-correlation of the neuromagnetic recordings in the Morlet wavelet domain and image the dynamic coherent sources across multiple frequency bands during the task. Moreover, the dipole orientation has a closed-form solution by applying the maximum-normalized-correlation criterion. Experiments with simulation and real data are conducted to verify the effectiveness of the proposed methods. According to our experiments with simulation data, the proposed method can efficiently and accurately calculate the dipole orientation and then can locate the sources with significant time-frequency coherence. When applied to a finger-lifting study, F-statistic map computed from the reconstructed neuronal activities on the cortical surface clearly identify the sensorimotor area with high contrast.

7-48: Spatial-temporal regularization of distributed sources in realistic head models
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When analyzing measurements from neurophysiological experiments, the question arises, which are the underlying neuronal sources. In the case of EEG/MEG, a common method for estimating these sources is the distributed source model approach. Usually, to solve this generally non-unique inverse problem, a spatial regularization is performed which does not use any temporal information. The main purpose of this work is to present a method for spatial-temporal regularization and to show and quantify its benefit in comparison to pure spatial approaches. The principle of spatio-temporal regularization was applied to several known methods of distributed source analysis and tested in a series of computer simulations. In particular, the following methods were evaluated: Weighted Minimum Norm, LORETA (LOw REsolution TomogrAphy), sLORETA (standardized), eLORETA (exact), LAURA (Local AUto Regressive Averages). All simulations were based on a standard realistic head model (3-layer Boundary-Element-Model). Two simultaneously active sources were placed in the left/right temporal lobe. They had similar but temporally shifted activation patterns, thus mimicking the situation in real experiment with monaural auditory stimulation. Applying spatial-temporal regularization decreased the error in source position and shape of the reconstructed source-waveform significantly for all methods, as compared to sole spatial regularization. The
localization error due to spatial-temporal regularization was reduced by up to one-third in comparison to pure spatial regularization (in the present of 30 percent gaussian amplitude noise, SNR=12). Note, that these results cannot be achieved by filtering of the data prior to source reconstruction [1][1] Schmitt, Numerical Aspects of Spatio-Temporal Current Density Reconstruction from EEG-/MEG-Data, IEEE TRANSACTIONS ON MEDICAL IMAGING, Vol. 20, 2001

7-49: Large-scale parameter estimation and dynamic source localization for the magnetoencephalography (MEG) inverse problem

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Dynamic estimation methods based on linear state-space models have been applied to the inverse problem in magnetoencephalography (MEG), and can improve source localization compared with static methods by incorporating temporal continuity as a constraint. The efficacy of these methods is influenced by how well the state-space model approximates the dynamics of the underlying brain current sources. While some components of the state-space model can be defined from brain anatomy and knowledge of the noise structure, parameters governing the temporal evolution of underlying current sources, i.e. the state noise covariance matrix, are unknown and must be chosen on an ad-hoc basis or estimated from data. We previously applied the Expectation-Maximization (EM) algorithm to estimate the state noise covariance matrix and dipole sources in an MEG state-space model, and demonstrated in small-scale simulation studies that the resulting source estimates were superior to those provided by static Minimum Norm Estimate (MNE) or dynamic Fixed-Interval Smoother (FIS) employing ad hoc parameter selection. In this work, we extend our previous result to demonstrate that the EM algorithm outperforms the MNE and FIS methods both in a large-scale simulation study and in an analysis of human experimental data. Our findings indicate that parameter estimation paired with dynamic source localization can produce a more accurate representation of the source distribution in the MEG inverse problem than other static and dynamic methods.

7-50: Algebraic reconstruction of multiple equivalent current dipoles using gradiometers on the upper hemisphere

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Objective The usual parametric approaches in MEG inversion, such as the nonlinear least squares method or MUSIC, employ iterative computations[1]. In contrast, we have proposed a direct method in which the equivalent current dipoles (ECDs) are localized algebraically from MEG data [2]. However, the method required magnetometers which surrounded the whole head. The aim of this paper is to extend our method to one using the gradiometers on the upper hemisphere only, which is more applicable to the actual situation. Methods In the direct method, the multipole moments (MMs) of MEG are necessary. First, we derive a relationship between the weighted integral of magnetometer data and gradiometer data so that MMs can be computed using the gradiometers. Second, we examine the order of MMs which can be accurately computed when the sensors are restricted to the upper hemisphere only. The localization results are compared when the different pairs of the MMs with/without the zero-th order are used. Results First, a simple formula to compute the MMs with the gradiometers was derived. Second, it was shown that accuracy of the zero-th order MM was worse than that of higher order MMs when the sensors were placed on the upper hemisphere, especially when the ECD existed close to the equatorial plane. Furthermore, it was shown that the localization accuracy as well as efficiency to estimate the number of ECDs were improved by using MMs higher than the first order. The method was verified using PHANTOM data and SEF data. Conclusion We established an inversion method in which the ECD parameters are reconstructed algebraically using data of gradiometers distributed on the upper hemisphere. References [1] S. Baillet et al., IEEE Signal Processing Magazine, 14-30, Nov. 2001. [2] T. Nara et al., Physics in Medicine and Biology, 52, 3859-3879, 2007.