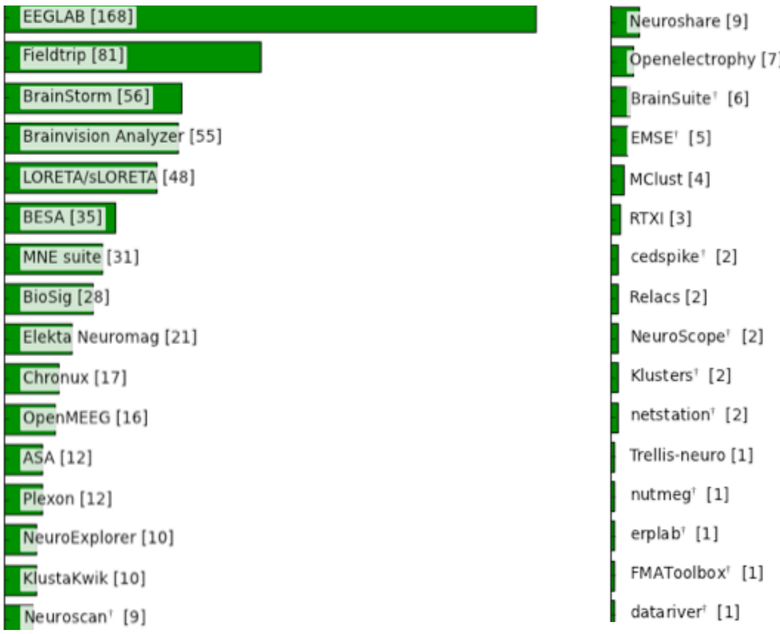
A survey of cognitive neuroscientists conducted in May, 2011 by Michael Hanke and Yaroslov Halcenko of Dartmouth College (Hanke & Helcencko, 2011) have reported that EEGLAB is now the most commonly used electrophysiological data analysis software, as shown below:



(from http://neuro.debian.net/survey/2011/results.html)

Above, the environment reported second most widespread use, fieldtrip, was developed and is supported from the Donders Center, Nijmegen, The Netherlands by our collaborator Robert Oostenveld and colleagues; the third, BrainStorm, was developed at USC and in France; the fourth is a commercial product from Germany; the fifth and sixth were developed as tools for inverse source modeling in Cuba/Switzerland and Germany, respectively.

Below we detail our progress in fulfilling our Specific Aims for development (SP1-SP8)

SP1) Signal processing and source localization: *We will continue to implement new methods for spatial filtering, including decomposing data into independent components, computing time-frequency data transforms, and performing advanced forward and inverse EEG and MEG source modeling using either standard template or individual subject structural magnetic resonance (MR) head images. We will also provide a more extensive framework of tools to assist users in adding and distributing their own data analysis tools.*

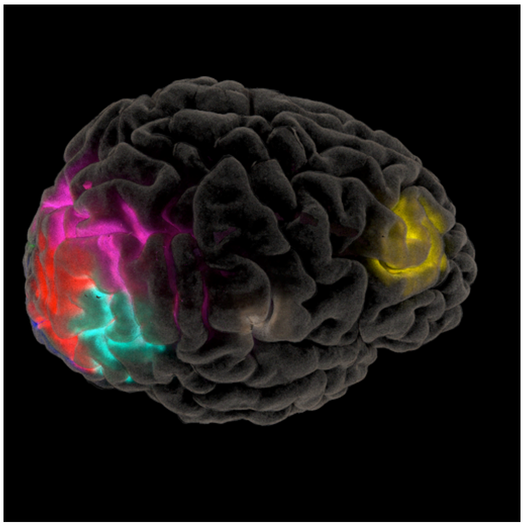
Realistic forward problem head modeling, the NFT toolbox: We have developed a comprehensive forward modeling toolbox, the Neuroelectromagnetic Forward Head Modeling Toolbox (NFT). NFT is compatible with EEGLAB and built on top of EEGLAB. NFT includes electrical modeling of human head, segmentation, mesh generation, electrode co-registration, warping of a template head model (MNI head model), forward problem solution using Boundary Element Method (BEM) and Finite Element Method (FEM), and single dipole source localization. The first version of NFT was released by author Zeynep Akalin Acar in 2009. After it's first release, FEM modeling and new high-resolution template models were added. Since last year, we tested the performance of FEM modeling and compared the source localization with BEM solutions. We also performed source localization comparisons using high-resolution MNI models with realistic head models. Recent improvements in mesh generation allow users to obtain topologically correct meshes. Improvements in co-registration of electrode locations speed-up automatic co-registration and improve accuracy. Various other small improvements have responded to bug reports of users. We are about to add anisotropy modeling in white matter in FEM modeling. A paper is under preparation using NFT to investigate differences in source localization using individualized versus template head models. An NIH proposal to use NFT to develop an age-indexed developmental template head facility is under revision.

SIFT. The Source Information Flow Toolbox (SIFT) is a collection of tools for modeling and visualizing (Granger-causal and other) information flow dynamics between identified sources of EEG data, generally after separating the data into source processes using BSS techniques such as ICA. The toolbox, developed and released by author Tim Mullen was released in 2009 and is built on top of EEGLAB. Recent improvements in this toolbox are the following:

- With statistician Wes Thompson of UCSD we are currently developing an improved novel Bayesian approach for joint estimation of the most likely source locations and connectivity graph -- with robust confidence intervals -- across a subject population. A preliminary demonstration of the approach on 24 subjects performing a two-back task has been reported in a conference abstract (Thompson, Mullen et al., 2011, ICON XI, *Frontiers in Human Neuroscience*). A related journal paper is being prepared.
- We are currently evaluating the relative suitability of various source estimation algorithms when combined with MVAR-based connectivity algorithms, and will further develop the toolbox accordingly.
- SIFT may help find transient, dynamic network events that link spatially static source processes (e.g., partially-synchronous activity within cortical patches). We have now developed fast routines for sparse multivariate autoregression and will soon incorporate additional cubature Kalman filter-based routines for improved detection of transient granger-causal couplings in (typical) non-stationary processes.
- The modular architecture of the toolbox is also designed to allow easy addition of new methods by the user community. In particular, SIFT may also be used for effective connectivity analysis and visualization of phenomena in single- or multi-trial electrocorticographic (ECoG) data, e.g. to identify sources and directions of information flow at onsets of and during epileptic seizures. We have demonstrated one such clinical application in a recent IEEE EMBC paper (Mullen et al, 2011).
- A 70-page online and .pdf-downloadable handbook has been developed and is under continuing development along with a website for SIFT (sccn.ucsd.edu/wiki/SIFT). SIFT has been downloaded from this website 205 times since 08-15-2011.

SP2) Analysis of large studies and parallel processing: *We will maintain and extend the recently introduced EEGLAB 'STUDY' structure, allowing users to directly apply a wide range of signal processing and statistical analyses to EEGLAB 'study sets' comprised of related datasets for any* *numbers of subjects, subject groups, sessions, and/or conditions. We will study and implement processing methods, exploiting the continued growth and wider availability of parallel processing resources by allowing and encouraging the use of parallel processing in processing EEGLAB studies.*

In 2010, Christian Kothe in our laboratory developed a parallel processing backend for general use throughout EEGLAB (relying on Java). We have also some implemented evolved parallel processing infrastructure dedicated to AMICA processing (see AMICA plug-in in this report), which includes a reserved cluster queue setup with 7+ nodes (each 32 cores) dedicated to parallel AMICA processing using OpenMP and MPI.



In the GPU-programming direction, we have made some progress in utilizing a GPU-based workstation for high-end visualization: Yi Liu and colleagues have developed a photon mapping based brain activity rendering software (The SCCN Glass Brain). A work-in-progress picture is attached (Figure 1). This new visualization technique will eventually be integrated into EEGLAB.

Figure 1. SCCN Glass brain currently under development for publication-quality source visualization using GPUs to perform ray tracing and materials modeling.

We have also greatly improved the stability of EEGLAB for processing large numbers of subjects within the EEGLAB STUDY structure. In particular, we have reprogrammed parts of the STUDY processing pipeline to ensure that all processing is performed accurately (involving changes to some thousands of lines of code). We have also made EEGLAB compatible with Octave for running using supercomputers on which Matlab is not available (see SP9 below).

SP3) Multi-modality imaging: *We will develop, introduce, and maintain methods for storing and analyzing electrophysiological data recorded separately from or concurrently with other imaging and physiological data streams including other electromagnetic, functional imaging, subject body motion capture, eye tracking, video, and/or autonomic measures.*

Combining Motion Capture and EEG data via MoBILAB: We have developed capabilities to expand the EEGLAB framework to allow loading, preprocessing, visualizing, and analyzing body motion capture (mocap) and/or other parallel data streams recorded simultaneously in EEG, a direction we call Mobile Brain/Body Imaging (MoBI) (Makeig et al., 2009) that we are developing under separate funding from ARL, NSF, and ONR. We had already started to implement these features in 2008 and are now offering public release through our laboratory web sites since 2009. In 2011, the MoBILAB environment for Matlab has been augmented to handle generic mobile brain/body imaging (MoBI) data recorded by the DataRiver software (A. Vankov) that we also develop and distribute. The MoBILAB environment now imports data collected by DataRiver in either of its two formats, ".drf" and ".bdf", as well as in native MoBILAB format.

A keystone of MoBILAB is the MultiStream Browser, a tool for visualizing synchronously recorded data streams, for example EEG time series (in a streaming browser), motion capture marker positions (as a stick figure display), video footage in its own window, etc. An event window allows marking of events identified via any of the data windows. A second set of capabilities derives kinematic movements of the motion capture data, allowing selection of critical moments in the recorded kinematics. Events of interest are used to extract event-locked data epochs that are exported to EEGLAB for electrophysiological analysis.

SP4) Plug-in facility and script library: *We will evolve the current EEGLAB plug-in facility that allows quick development and web-based publication of new EEGLAB functions that immediately 'plug in' to the EEGLAB graphic user interface (GUI) of any user who downloads them. We will extend plug-ins to be able to operate on whole EEGLAB studies, and will introduce the ability to plug-in new options into complex analysis and display functions.*

Measure Projection Toolbox: The Measure Projection Toolbox (MPT) is an open source EEGLAB plug-in (or plugin) toolbox for probabilistic multi-subject EEG independent component source comparison and inference. Instead of representing equivalent dipole models for independent components as points, Measure Projection models each of them by a 3-D Gaussian probability density. Measure Projection Analysis (MPA) is a novel probabilistic multi-subject inference method that overcomes IC clustering issues by abandoning the notion of distinct IC clusters (Nima Shamlo-Bigdely et. al., submitted). Instead, it searches voxel by voxel for brain regions having event-related IC process dynamics that exhibit statistically significant consistency across subjects and/or sessions as quantified by the values of various EEG measures. Local-mean EEG measure values are then assigned to all such locations based on a probabilistic model of IC localization error and inter-subject anatomical and functional differences. MPA reduces the number of analysis parameters while avoiding over-simplifying the implicit neurophysiological assumptions of cluster-based analysis. In 2011, the toolbox readiness level was moved from beta to stable and the software was released on the Internet. In addition, new visualization options were developed.

AMICA and the AMICA EEGLAB plug-in: AMICA (Adaptive Mixture Independent Component Analysis) is an algorithm developed by Jason Palmer (2008) in our laboratory. Our recent comparison of 22 blind source separation methods applied to EEG data identified AMICA as more successful than all other existing algorithms by two criteria: it recovers component processes with minimum mutual information, and it returns more components whose scalp maps are compatible with an origin in a compact area of cortical local field synchrony (Delorme et al., in press).

Unlike regular ICA methods where only one mixing matrix is trained over the whole data, AMICA can return multiple mixing matrices (models) assuming that for each time point one of those models are active, hence adopting the name "mixture" ICA. Like other mixture models, together with mixing matrix coefficients, it returns the probabilities of each model being active at all time frames of the data, thus producing a probability time course for each model. AMICA plugin is written to analyze the data according to these probabilities in an easier way. An interface to easily run AMICA with many different parameter settings (number of models, number of iterations etc.) and loading the results into current EEG file was created in 2011. An interface for smoothing and plotting the probability time courses together with EEG events has also been created to observe the changes in AMICA models. An option to view the data together with the active AMICA model is incorporated. Some EEGLAB functions have been modified to be able to select or epoch the probability time courses together with data, so that they are always compatible and can be viewed together in a consistent way. Users may also select or discard the data where certain models are active or not active. Another feature of the plugin is to create an erpimage (over the epoched data) where active models are plotted as a function of time. This erpimage might be able to allow users to observe the switches in ICA models relating to specific events or stimuli. Regular plot for 2-D component maps has been modified such that now we can easily plot different models' scalp maps. Moreover, through GUI one can easily plot the pairwise mutual information matrix and see relatively dependent components in each model together with their scalp maps.

SP5) Shared data resource: *In collaboration with the San Diego Supercomputer Center Storage Research Broker data archiving facility and software development team, we will develop, and maintain a publicly available resource for well-documented EEG, MEG, and other EEGLAB studies.*

Together with Jeffrey Grethe of the National Center for Microscopy and Imaging Research at UCSD, we have developed a framework to implement a public sharing data resource, and have obtained an RO1 proposal under NIH PAR-07-426 ("Sharing Data and Tools: Federation using the BIRN and caBIG Infrastructures").

In 2011, our programmer Jeff Schmitz has built tools to convert an EEGLAB STUDY to an experimental design in the database. We currently have several systems that will be used to test automated synchronization using the iRODS framework. We have also developed a general web portal for the database using AJAX. Our AJAX front-end interfaces the database using the XCEDE XML framework which provides a REST based API through the Ruby on Rails web platform. We are in the process of implementing authentication and restricted database access using the now widely used OpenID identification mechanism. The database is available from within the laboratory for beta testing and we are planning to release it publically in 2012.

SP6) Interoperability: *We will maintain and as necessary extend existing EEGLAB functions and data structures to read and write EEGLAB data in formats used by leading data collection systems. We will maintain and/or develop functions to easily bridge EEGLAB to and from other freely available brain imaging packages.*

BCILAB. BCILAB is an open-source framework and EEGLAB plug-in built by Christian Kothe in our laboratory for the study of EEG and other biosignals using advanced methods from machine learning and signal processing. We have further improved the intergration between EEGLAB and the BCILAB toolbox. In particular, several core EEGLAB routines have been optimized to satisfy the performance requirements of BCILAB which include fast partitioning of data for cross-validation and nested cross-validation, as well as fast processing of signals and their meta-data for certain real-time operations (such as channel selection or spatial filtering). Secondly, a broader range of advanced EEGLAB functionality has been made accessible out-of-the-box within BCILAB, including montage coregistration, dipole fitting and various types of independent component analysis, including indepenent component mixture models (AMICA).

SP7) Code stability and maintenance: *We will continue to improve EEGLAB software maintenance tools and practices. We will organize the EEGLAB code base under the Gforge software repository and use the SVN (Subversion) framework for distributed development. With our consultants, we will build, maintain, and freely distribute an extensible suite of test functions in the Matlab Unit Testing framework.*

Code repository. The code repository is now being complemented with a wiki that references all the code edits (as of February 2011). This allows both users and developers to be aware of recent changes without having to use SVN commands.

Bugzilla. In 2011, we have restructured Bugzilla with better job assignment between the different EEGLAB developers. One junior developer filters the bugs and reproduced them before more experience developers fix them. This optimizes the time spent on fixing bugs.

Test suite. We have consolidated our test suite, and added about 100 test functions. These functions deal mainly with processing multiple subjects. The test suite now runs nightly on our server and send messages to EEGLAB developer in case a problem is encountered.

SP8) Documentation: *We will also continue to maintain and enhance the current hundreds of pages EEGLAB documentation which we will incorporate into a wiki using Wikimedia software to facilitate user corrections and additions. We will also publish a free downloadable user-validated manual.*

Tutorial documentation. We are still actively responding to dozens of email a week on the EEGLAB mailing list, a list that reaches about 4,500 (compare to 3,500 in 2010) electrophysiology researchers.

Video documentation. As part of our effort to reach more researchers, we have developed a virtual workshop containing video of presentation given at the UCSD EEGLAB workshop in November 2010.

Improved code repository documentation and access. In the EEGLAB tutorial wiki, we are now linking directly the latest version of EEGLAB functions available in the SVN repository. This is made possible by custom PHP scripts.

SP9) Open source community development: *We propose to develop a developer group and to offer training workshops to help us make EEGLAB as broadly useful to the field of electrophysiological research as possible.*

Octave. One of the major upgrade of 2011 has been to make the command line code of EEGLAB fully compatible with the Octave open source language. When it comes to using supercomputers, the cost of running Matlab may become prohibitive. We have attempted to tackle this problem and as of June 2011 (EEGLAB 10.2+), EEGLAB supports Octave (v3.4) for supercomputing applications (command line calls only, no graphic support). In our tests, Octave is about 50% slower than Matlab but this can easily be compensated by increasing the number of processors assigned to a specific processing task. As part of this upgrade, we have also submitted about 30 bug reports and improvements to the Octave community which has responded very positively.

Workshops. In 2011, we have offered two international workshops, one in France with 40 participants, and one in Mallorca, Spain with 110 participants. Both workshops were fully financed from participant registration fees.

References

Delorme, A., Mullen, T., Kothe, C., Bigdely-Shamlo, N., Akalin, Z., Vankov, A., Makeig, S. (2011) EEGLAB, MPT, NetSIFT, NFT, BCILAB, and ERICA: New tools for advanced EEG/MEG processing. Computational Intelligence, article ID 130714.

Gramann, K., Onton, J., Riccobon, D., Müller, H.J., Bardins, S., Makeig, S. (2010). Human brain dynamics accompanying use of egocentric and allocentric reference frames during navigation. *Journal of Cognitive Neuroscience*, 22(12), 2836-2849.

Gwin, J.T., Gramann, K., Makeig, S., Ferris, D.P. (2010). Removal of movement artifact from high-density EEG recorded during walking and running. *Journal of Neurophyiology*, 103, 3526-3534.

Previous Work Cited

M Hanke, YO Halchenko (2011) Neuroscience runs on GNU/Linux, *Frontiers in Neuroinformatics*, 5:8.