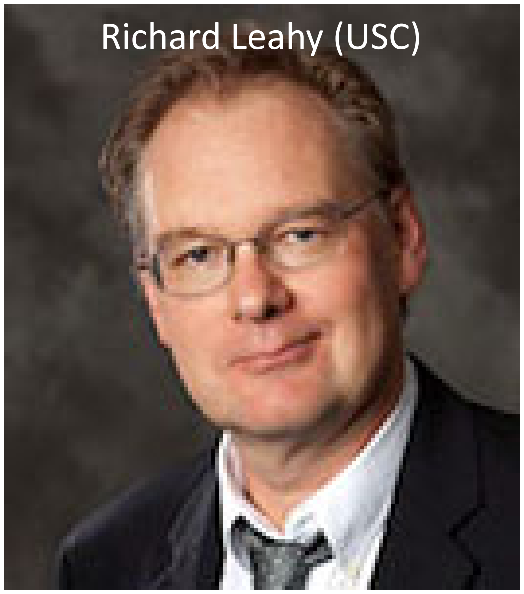


Brainstorm: MEG/EEG software since 2000

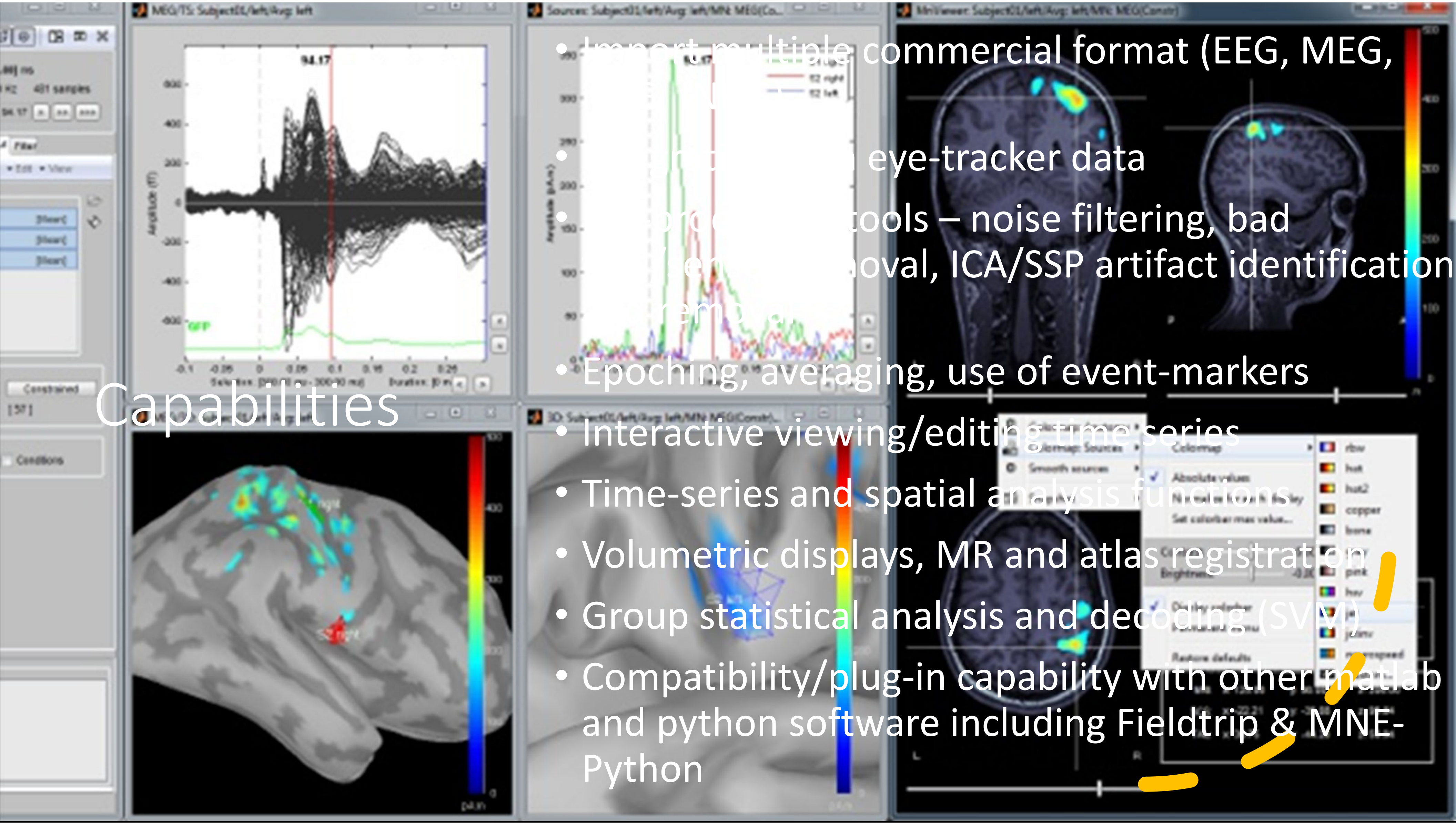
- Current team: Sylvain Baillet, John Mosher, Raymondo Cassani Gonzalez, Takfarinas Medani, Anand Joshi, Dimitrios Pantazis, Marc Lalancette, Chinmay Chinara, Anshul Gupta, Richard Leahy

Brainstorm Overview

- Matlab/Java software – highly interactive GUI environment & scripting capabilities
- Copious documentation through a large series of on-line tutorials:
  - https://neuroimage.usc.edu/brainstorm/Tutorials
- On-line video introductions
  - https://neuroimage.usc.edu/brainstorm/Introduction
- Tutorial publications

1. F Tadel, S Baillet, JC Mosher, D Pantazis, RM Leahy (2011) Brainstorm: a user-friendly application for MEG/EEG analysis. Computational intelligence and neuroscience, 1-13
2. S Baillet, JC Mosher, RM Leahy, Electromagnetic brain mapping (2001) IEEE Signal processing magazine 18 (6), 14-30
3. F Tadel, E Bock, G Niso, JC Mosher, M Cousineau, D Pantazis, RM Leahy, S Baillet (2019) MEG/EEG group analysis with brainstorm, Frontiers in neuroscience, 76

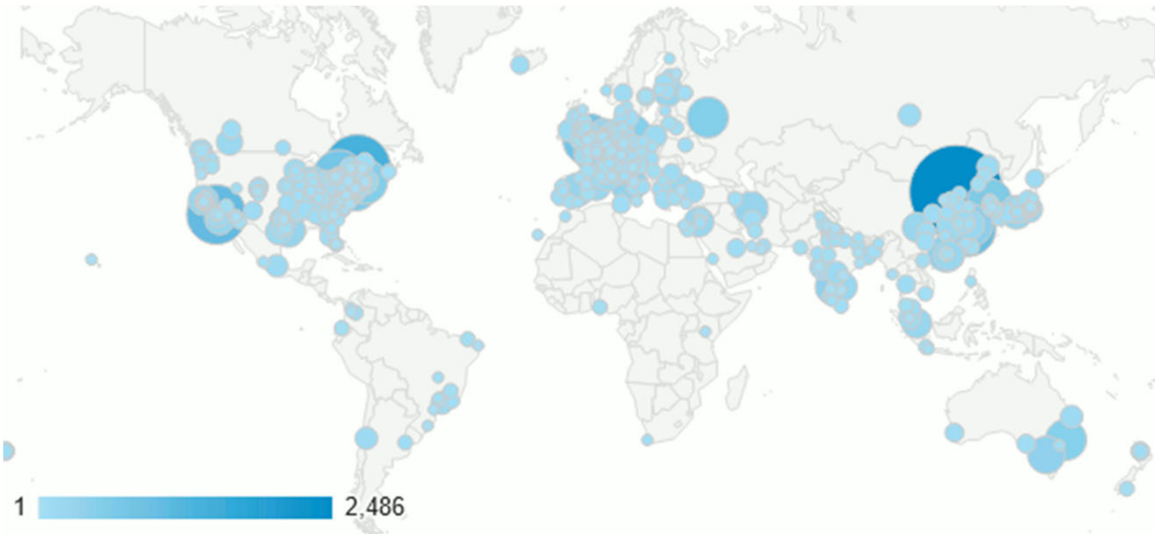
With the generous support of National Institute of Biomedical Imaging and Bioengineering: R01 EB026299, R01EB009048, R01 EB002010

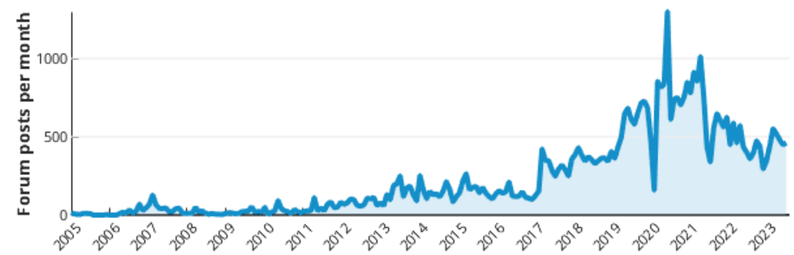


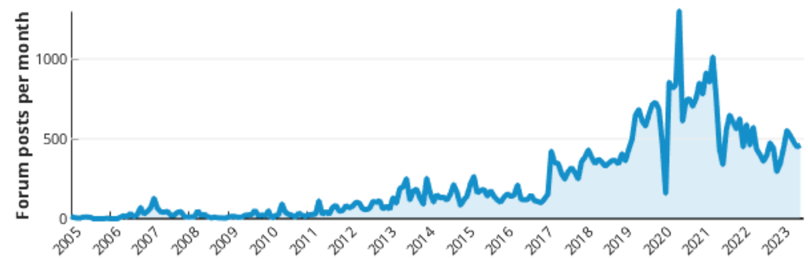
Capabilities

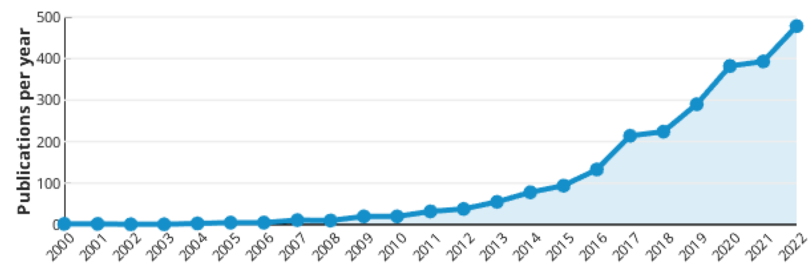
- Import multiple commercial format (EEG, MEG,
- eye-tracker data
- tools – noise filtering, bad oval, ICA/SSP artifact identification
- Epoching, averaging, use of event-markers
- Interactive viewing/editing time series
- Time-series and spatial analysis functions
- Volumetric displays, MR and atlas registration
- Group statistical analysis and decoding (SVM)
- Compatibility/plug-in capability with other matlab and python software including Fieldtrip & MNE-Python

The Brainstorm Community

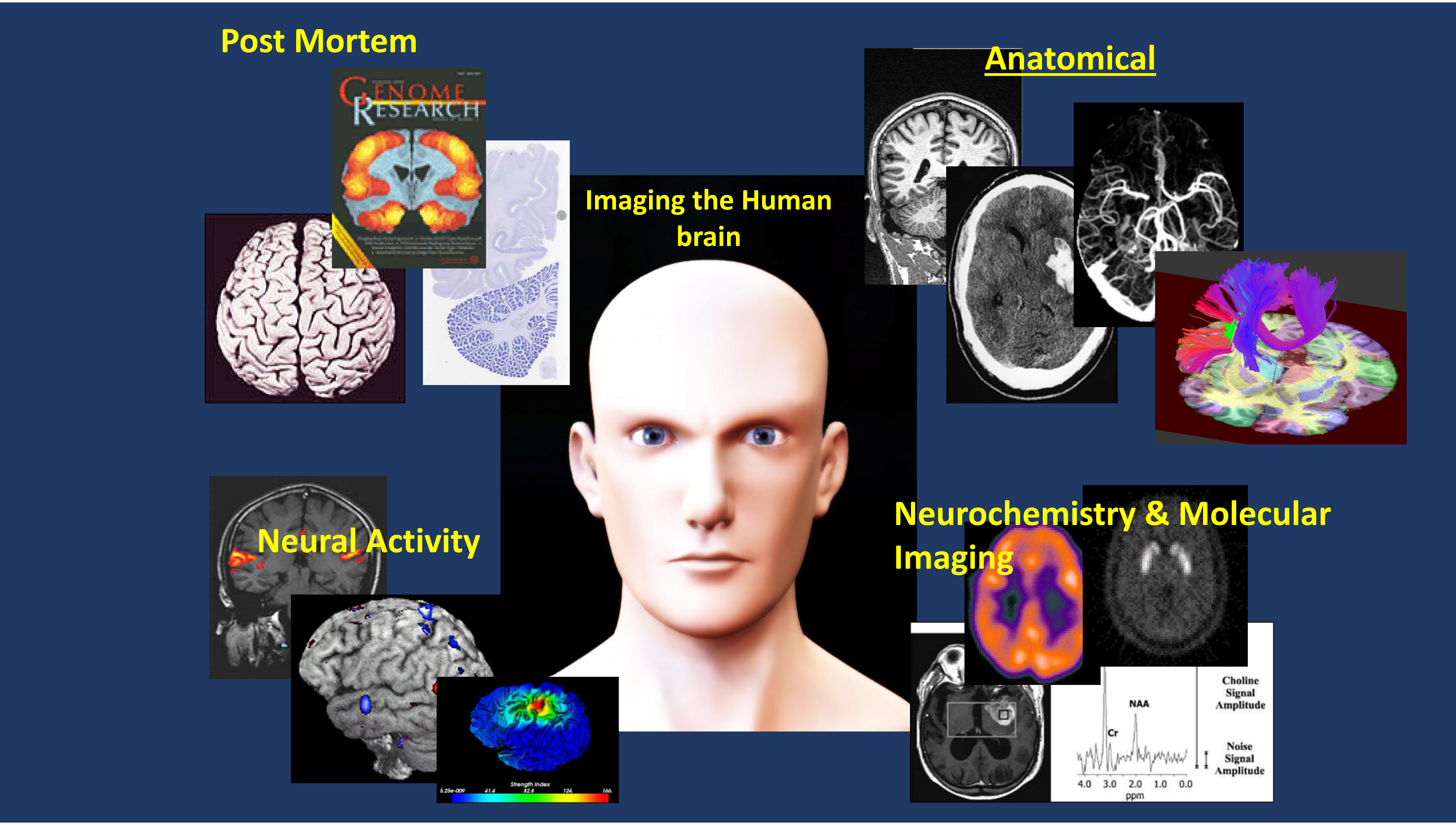








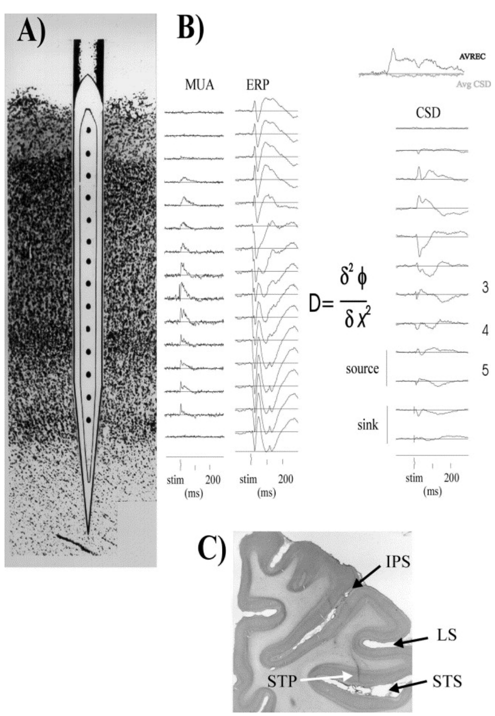
Data


Post Mortem
GENOME RESEARCH
Anatomical
Imaging the Human brain
Neural Activity
Strength Index
Neurochemistry & Molecular Imaging
NAA
Cr
Choline Signal Amplitude
Noise Signal Amplitude
4.0 3.0 2.0 1.0 0.0
ppm

Electromagnetic recordings

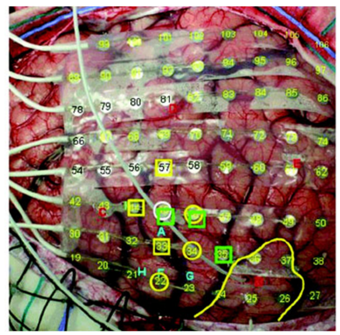
100-1000micron — 1-10mm — 1cm-10cm

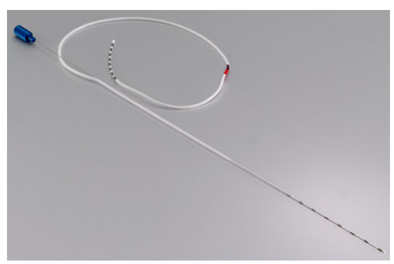
Micro electrodes



Depth Electrode

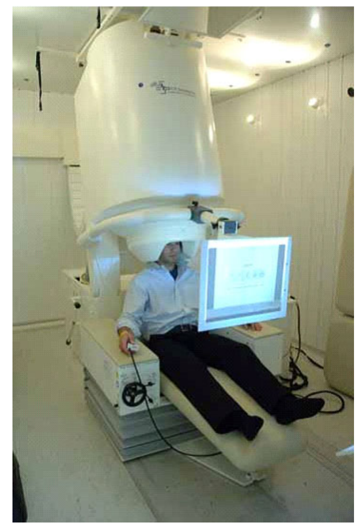
ECoG



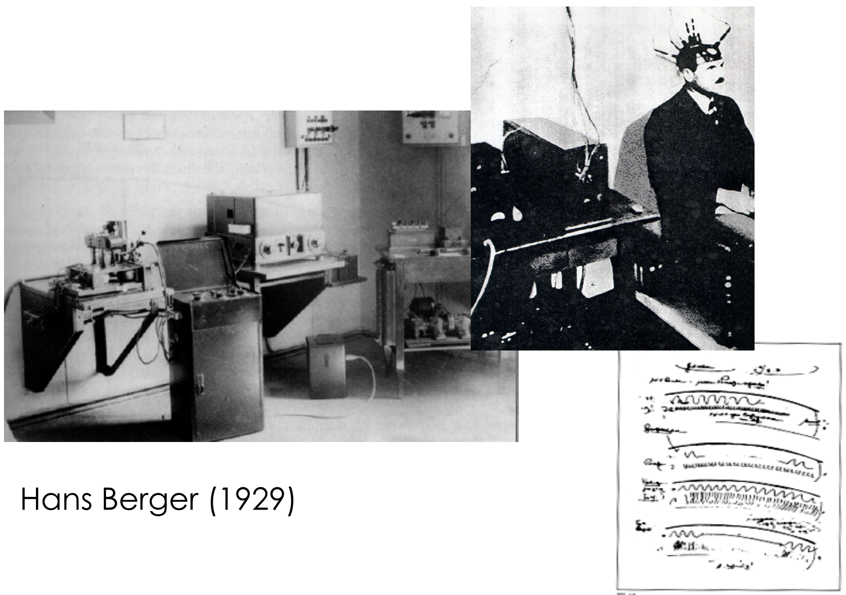


MEG

EEG

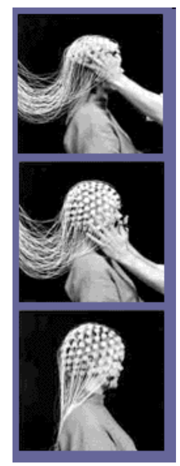


Electroencephalography (EEG)



Hans Berger (1929)

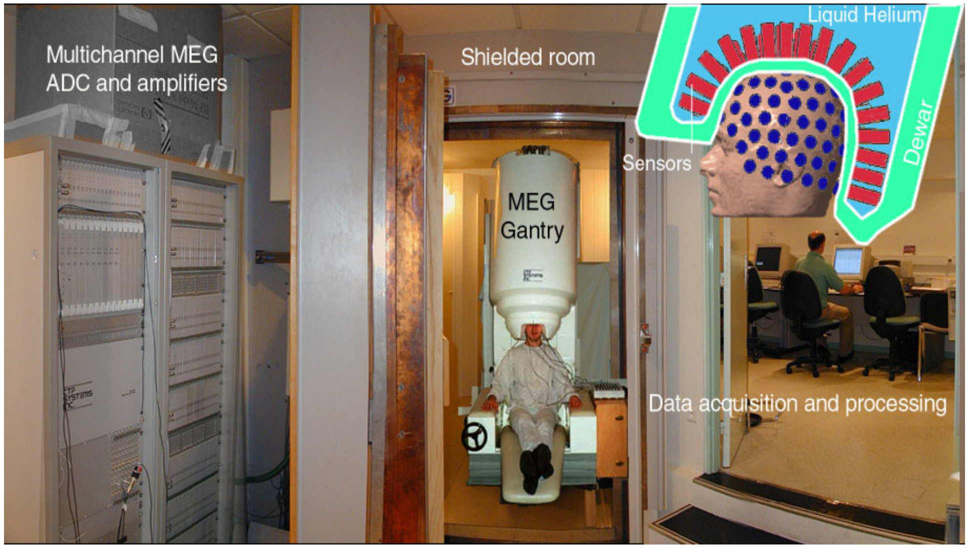
Wearable Sensing

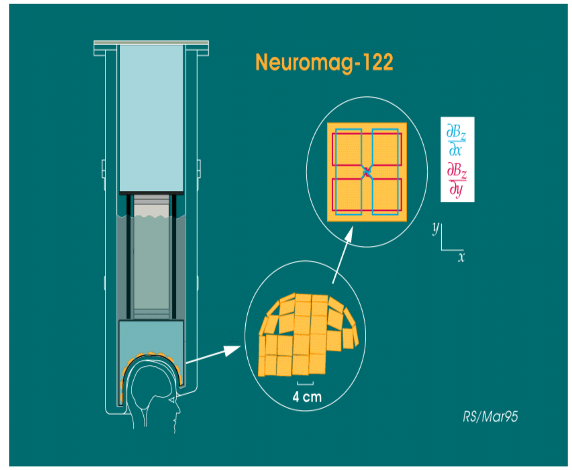


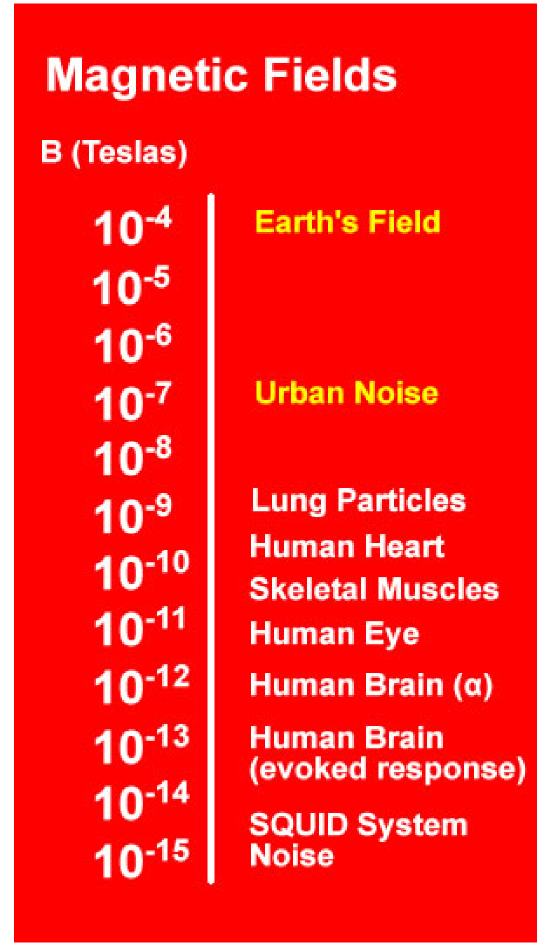
Electrical Geodesics

NeuroScan

Magnetoencephalography (MEG)



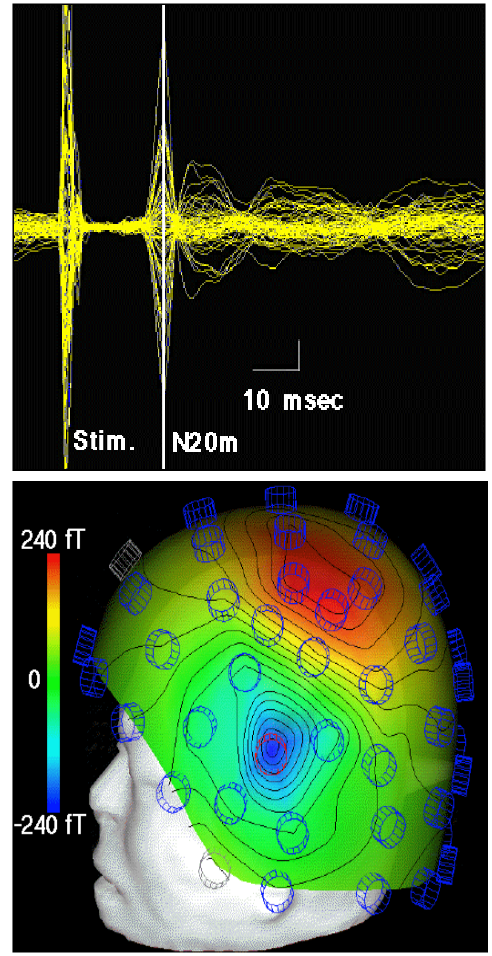




- MEG signals ~ 50-500fT (Earth's magnetic field ~50mT)
- Detected using SQUID magnetometers
- Gradiometers and magnetic screening reduce interference

Data

- **Temporal:** Averaged event-related signals - high temporal resolution monitoring of neural activation
- **Spatial:** Snap-shot topographic maps of external magnetic fields
- **Problem:** Explore relationship between neuronal sources in space and time and task or mental/neurological disorder
  - Evoked or event related studies
  - Naturalistic stimuli
  - Resting-state
  - Hyper-scanning



Median nerve stimulation (MEG)

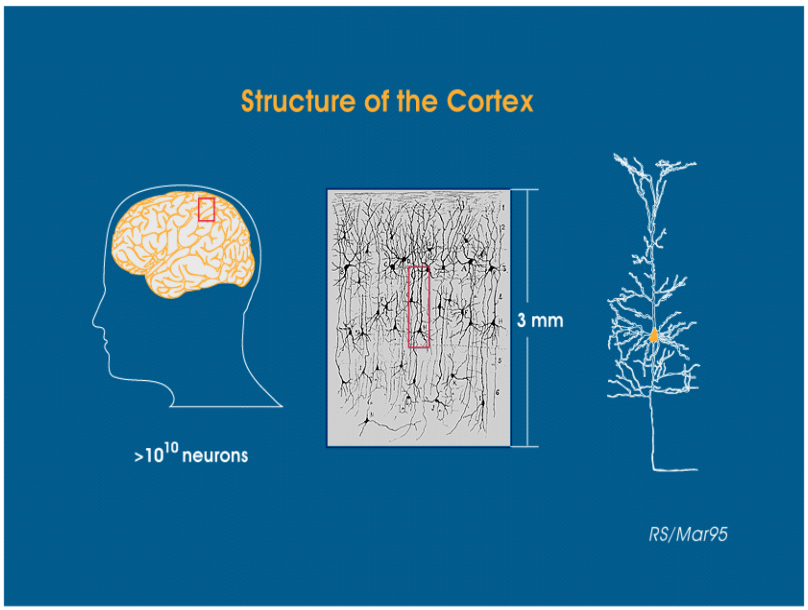
Challenges

- High temporal-resolution low spatial-resolution data
- Extraction of time-series features
  - Evoked potentials
  - Time-frequency analysis
  - Connectivity analysis
- Spatial localization
  - Lead-field sensitivity and forward models
  - Inverse solutions
  - Identifying regional sources
- Statistical Analysis
  - Individual vs. group analysis
  - Parametric vs. nonparametric methods
  - ANOVA and GLMs
  - Machine Learning for regression, classification and prediction (tomorrow!)

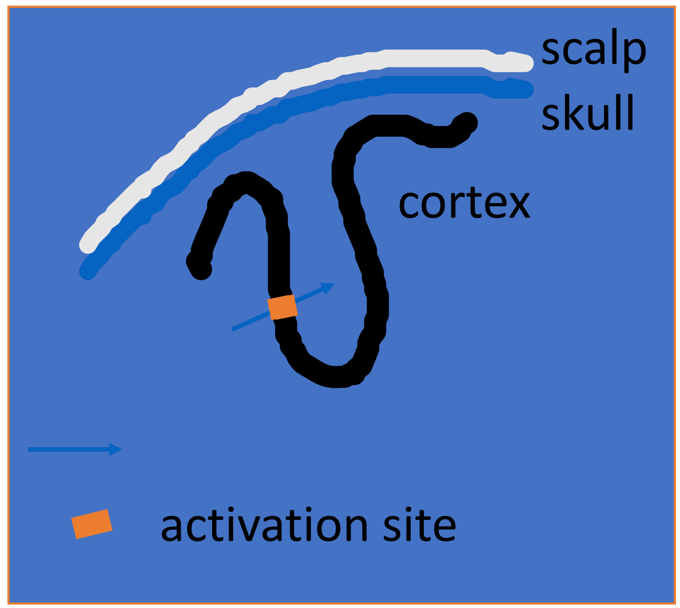
Source Estimation

Sources of the EEG and MEG Signal

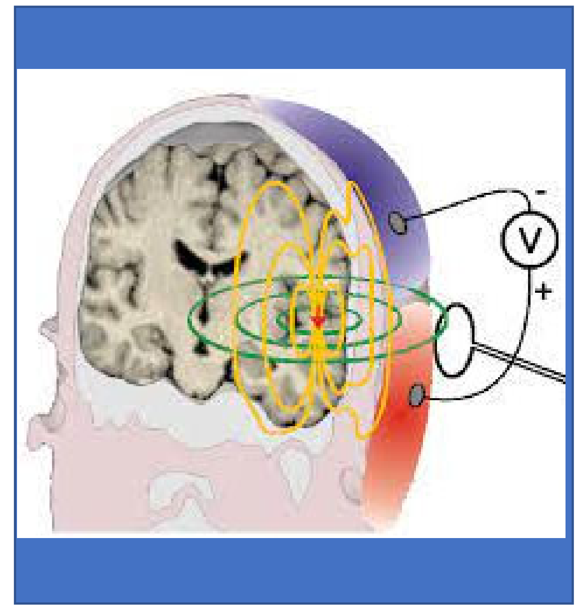
Scalp potentials and extra-cranial magnetic fields are produced by current flow in apical dendrites in cortical pyramidal neurons



from Ritta Salmelin, low temperature lab, Helsinki university of Technology

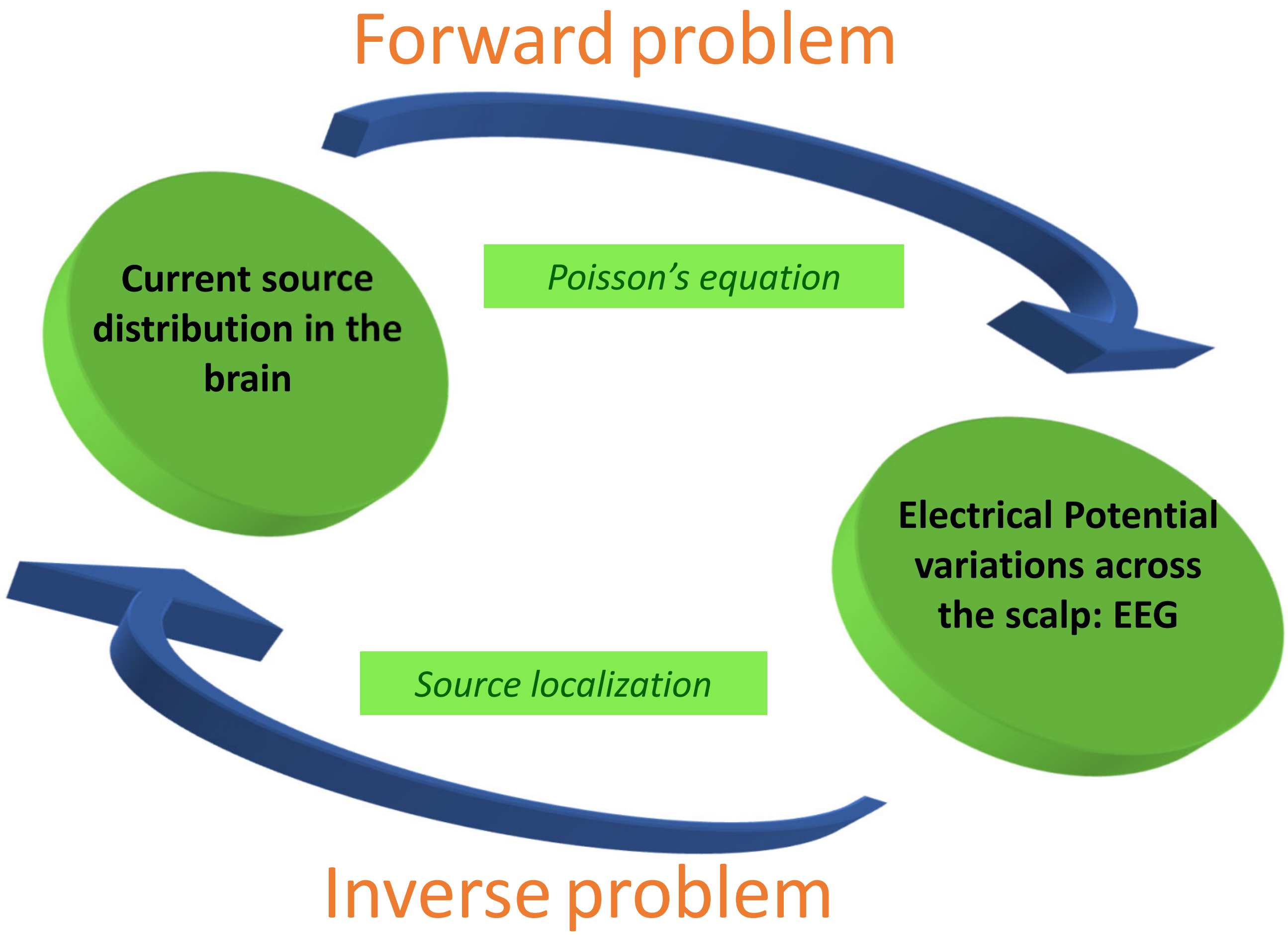


Columnar organization of cortex and spatial functional specialization on cortical surface lead to ***current dipole* model** fpr focal regions of activation



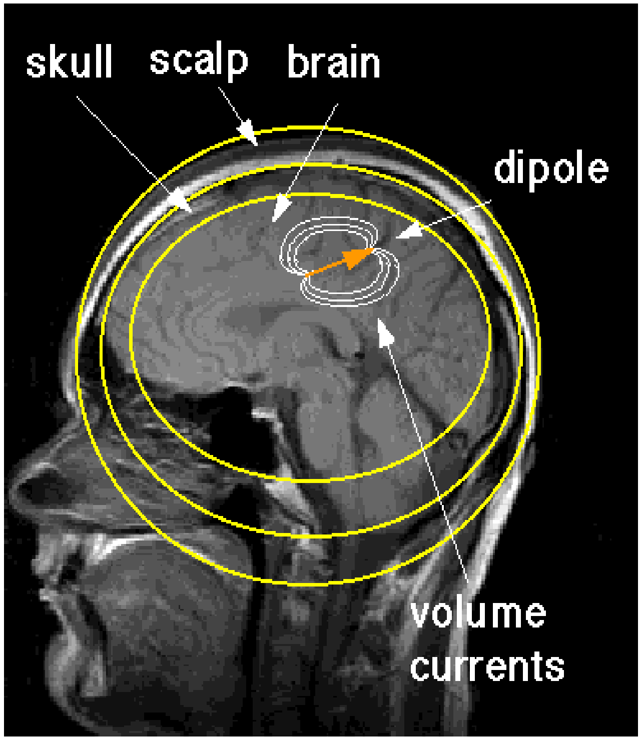
Volume currents from dipole pass through the skull to produce spatial varying potentials on the scalp and the EEG

Forward and Inverse Problems

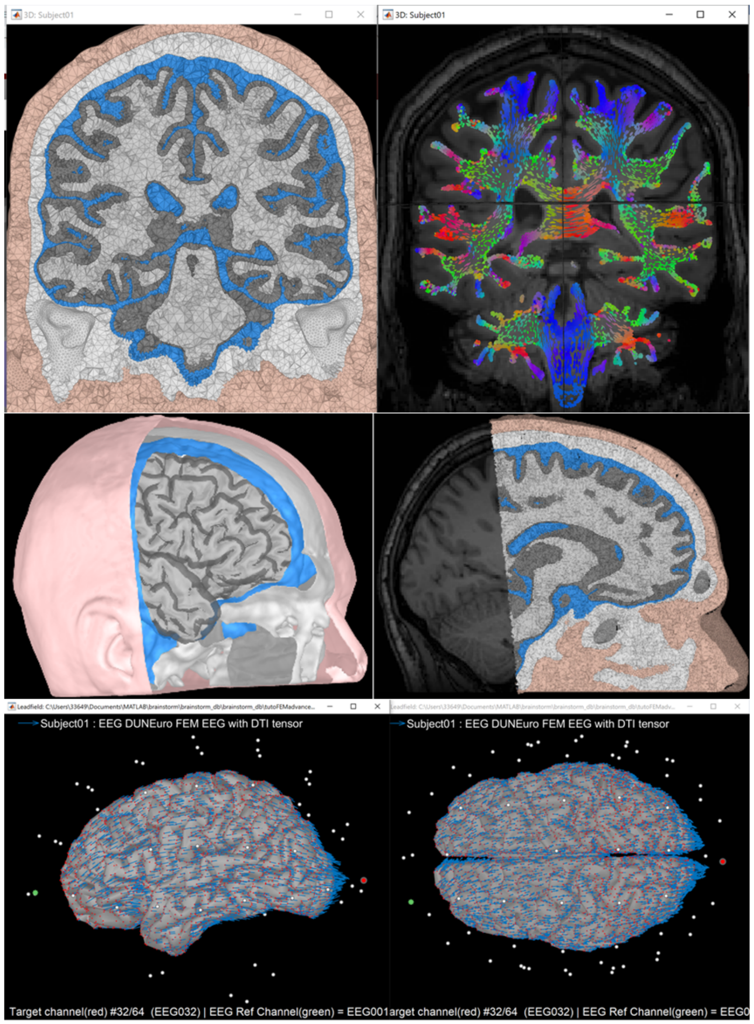


Forward Models

- Use quasistatic EM model to map from current source to measured fields
- Interested in "primary" rather than "volume" currents
- Spherical head: closed form
- Real head shape & cond-uctivity from MR: use BEM or FEM



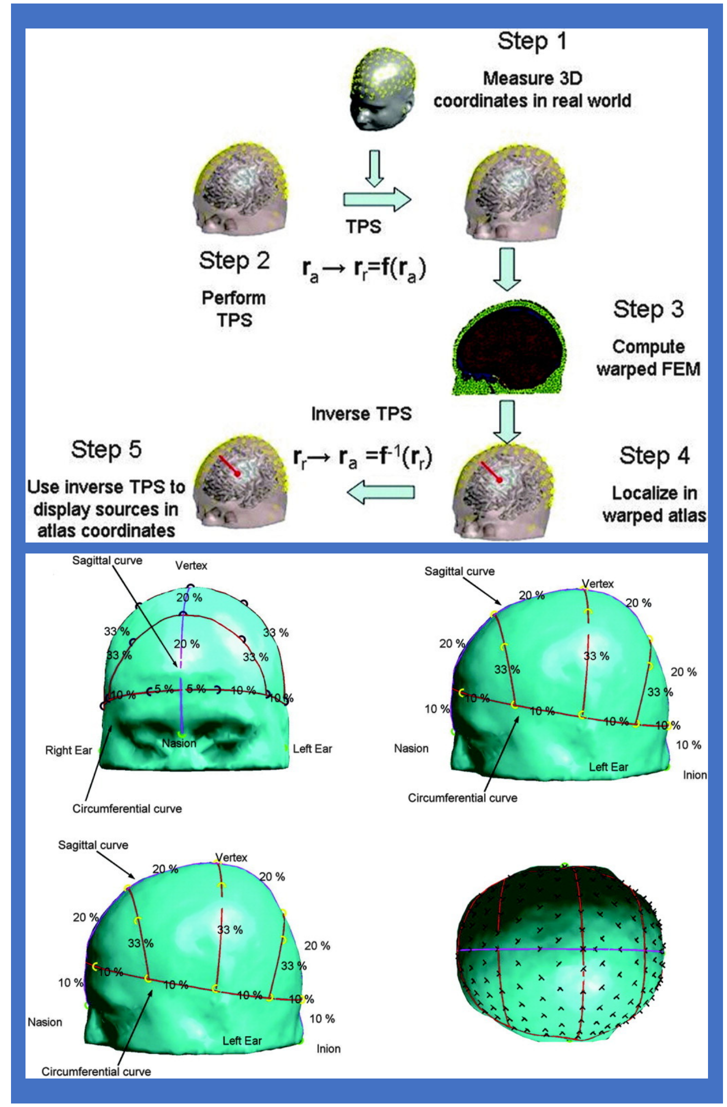
Individualized Forward Models



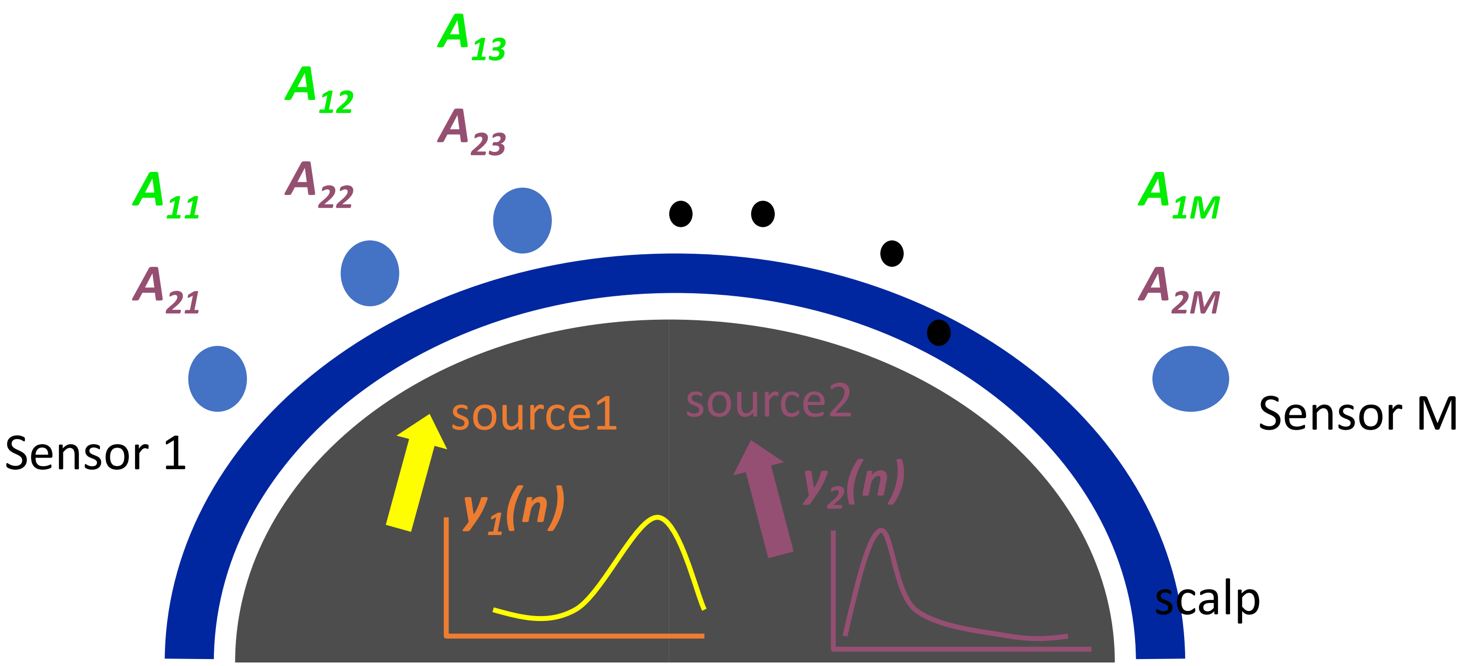
Detailed forward model based on segmented MRI with anisotropic diffusion from DW-MRI

Lower panel shows lead-field sensitivity for a pair of electrodes

In absence of individual MRI, use Polhemus localized to map scalp coordinates and warp atlas to individual subject

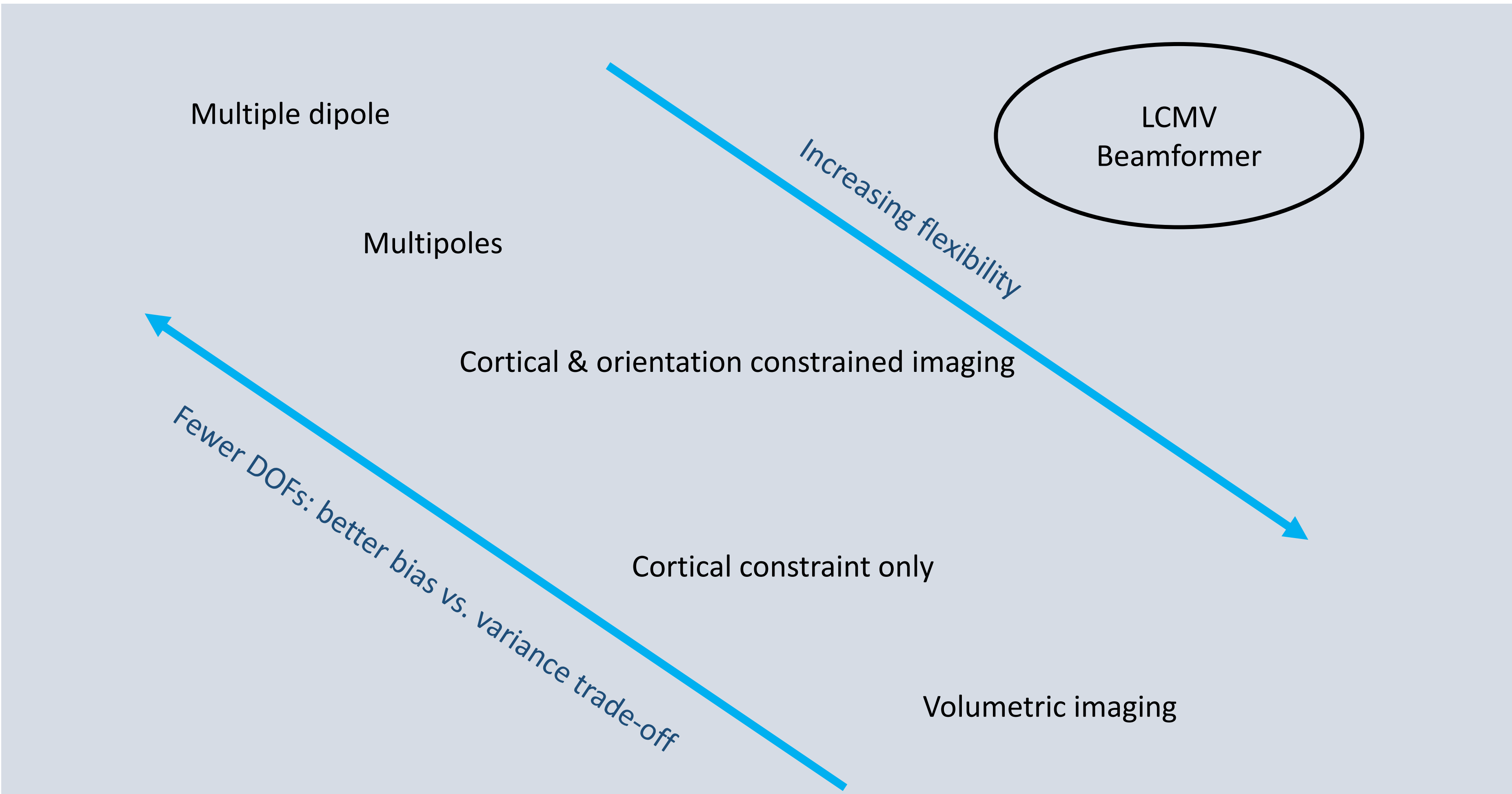


The inverse problem for multiple sources



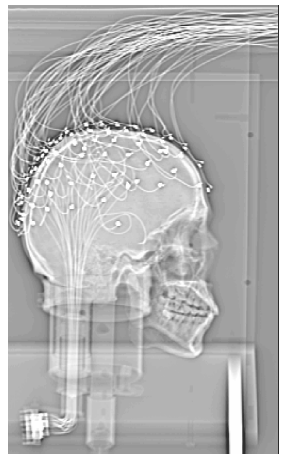
$$\begin{bmatrix} \mathbf{b_1(n)} \\ \vdots \\ \mathbf{b_M(n)} \end{bmatrix} = \begin{bmatrix} \mathbf{A_{11}} & \mathbf{A_{21}} \\ \vdots & \vdots \\ \mathbf{A_{1M}} & \mathbf{A_{2M}} \end{bmatrix} \begin{bmatrix} \mathbf{y_1(n)} \\ \mathbf{y_2(n)} \end{bmatrix} \quad n = 1, \dots N$$

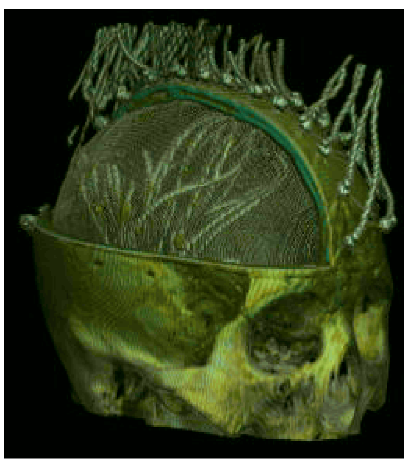
Explicit & Implicit Models

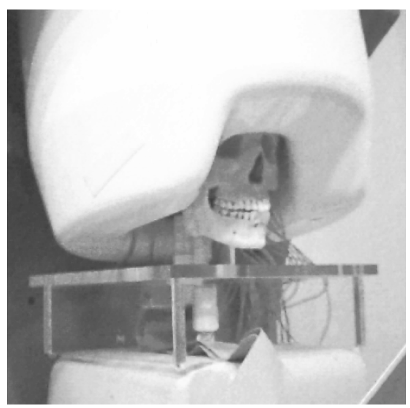


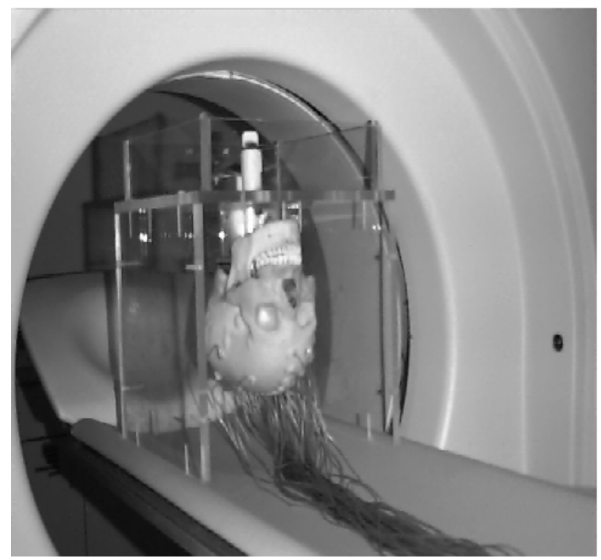
Phantom Study

- 32 current dipoles in human skull phantom
- Ground truth from CT scan
- MEG data from Neuromag-22
- Sources fit using R-MUSIC, spherical and realistic BEM forward models



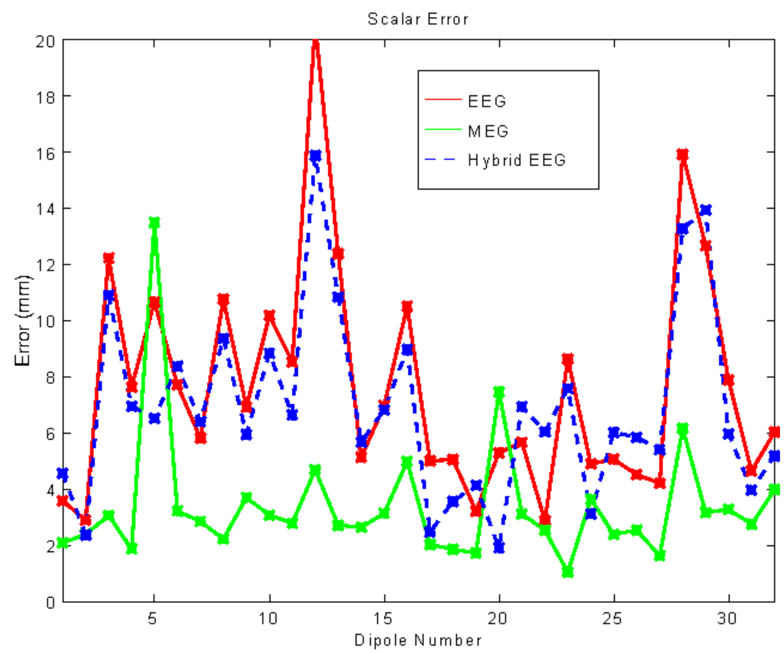


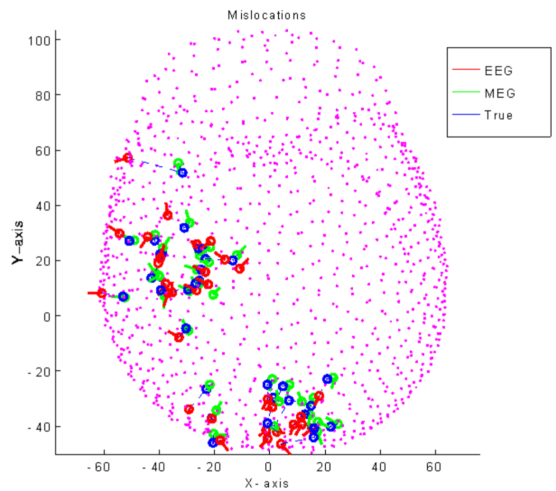




Phantom Localization Errors

- Average error for 32 dipoles using spherical head model: 4.1mm
- Average error for 32 dipoles using BEM head model: 3.4mm

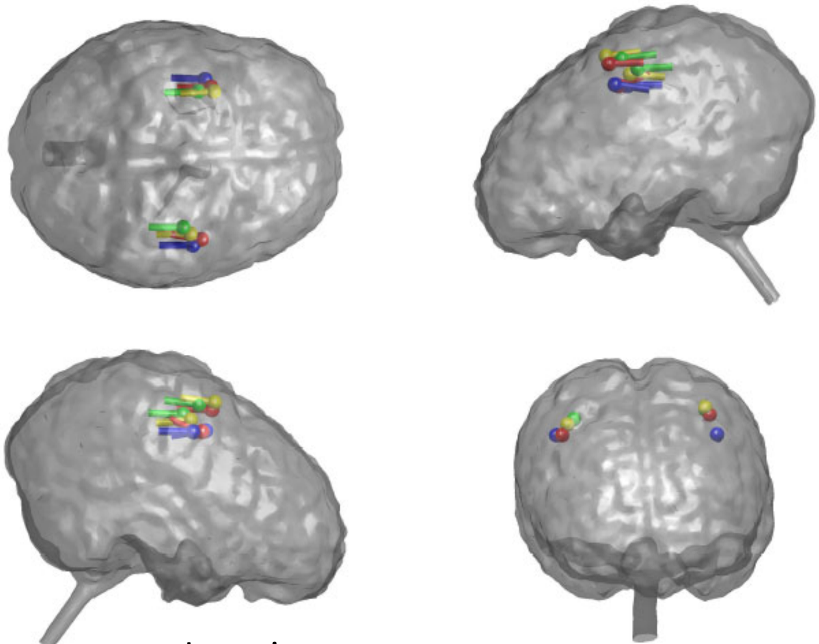




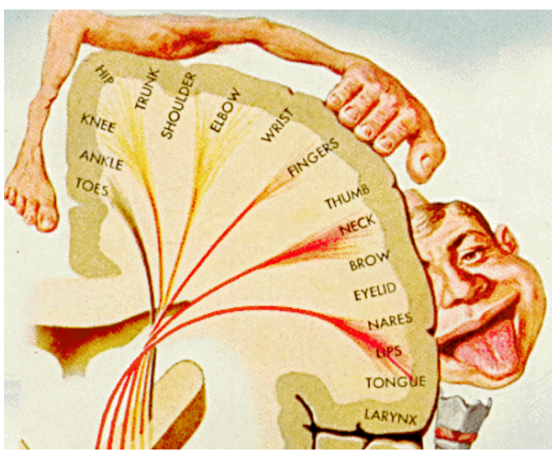
RM Leahy, JC Mosher, ME Spencer, MX Huang, JD Lewine (1998) A study of dipole localization accuracy for MEG and EEG using a human skull phantom, Electroencephalography and clinical neurophysiology 107 (2), 159-173

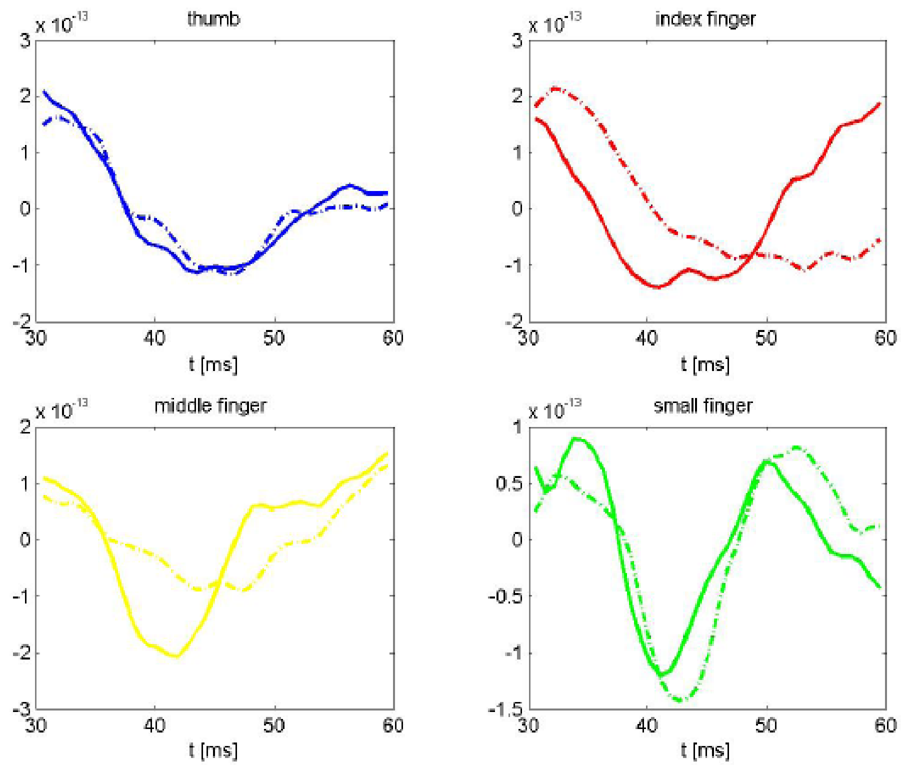
Somatosensory Stimulation & Localization

Electric stimulation of 4 digits of left and right hand



Locations

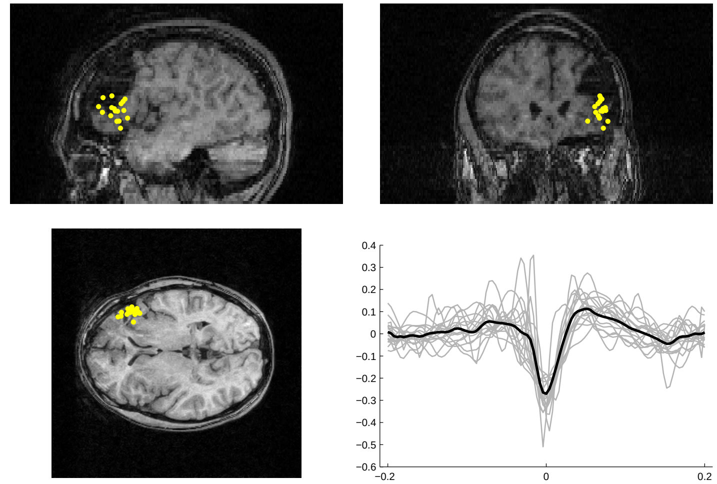




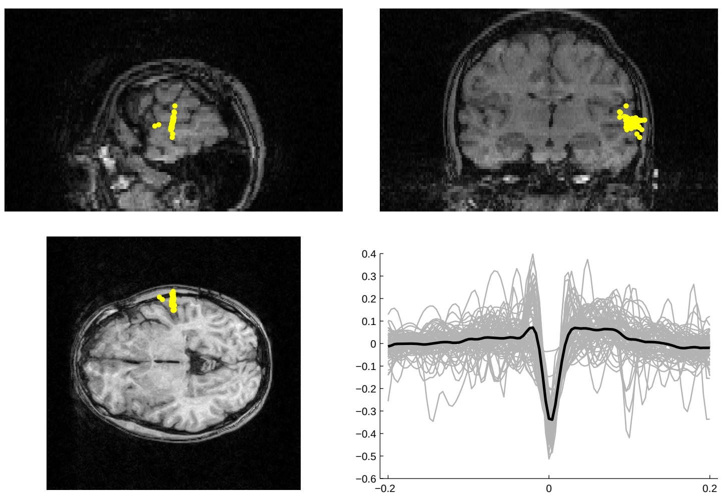
Time series

Source localization in Epilepsy

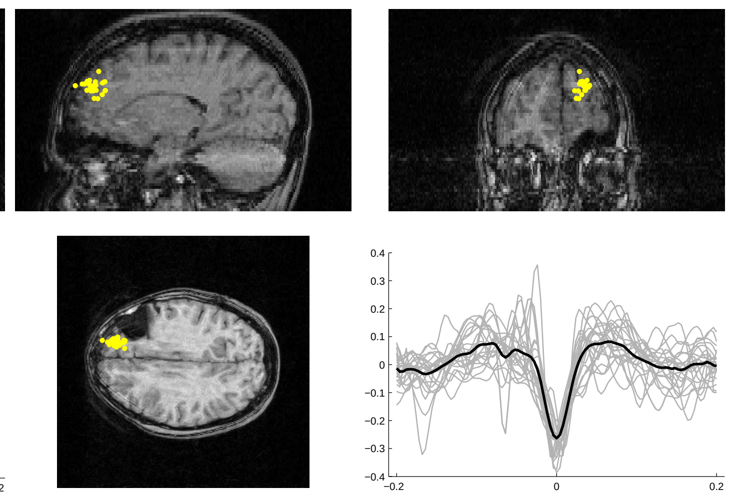
Automated noninvasive spike detection, localization and clustering from spontaneous interictal spikes



Cluster 2



Cluster 1



Cluster 3

Distributed solutions: Minimum Norm Imaging

Inverse solutions based on regularized least-squares

$$\min \|\mathbf{b} - \mathbf{A}\mathbf{y}\|_2^2 + \lambda \|\mathbf{W}\mathbf{y}\|_2^2$$

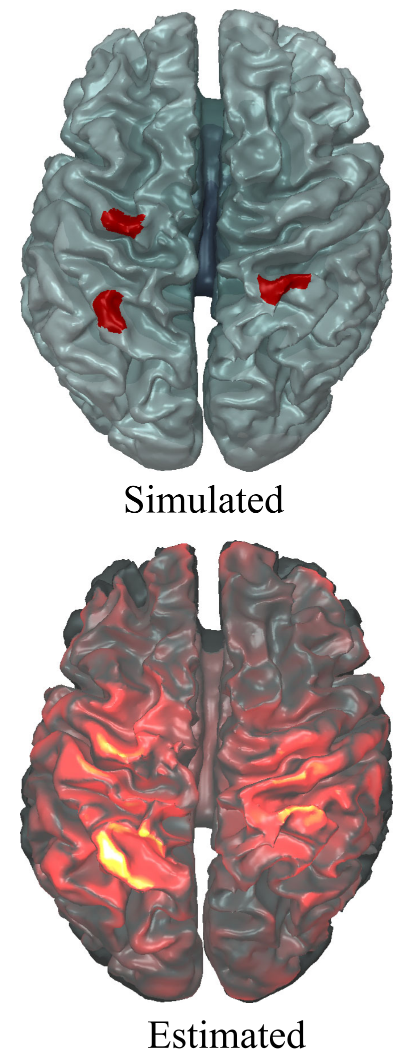
Possible regularizers

$$\mathbf{W} = \mathbf{I}$$

$$\mathbf{W} = \mathbf{W}_{\mathbf{norm}} = diag[1/\|a_1\|, \ldots, 1/\|a_N\|]$$

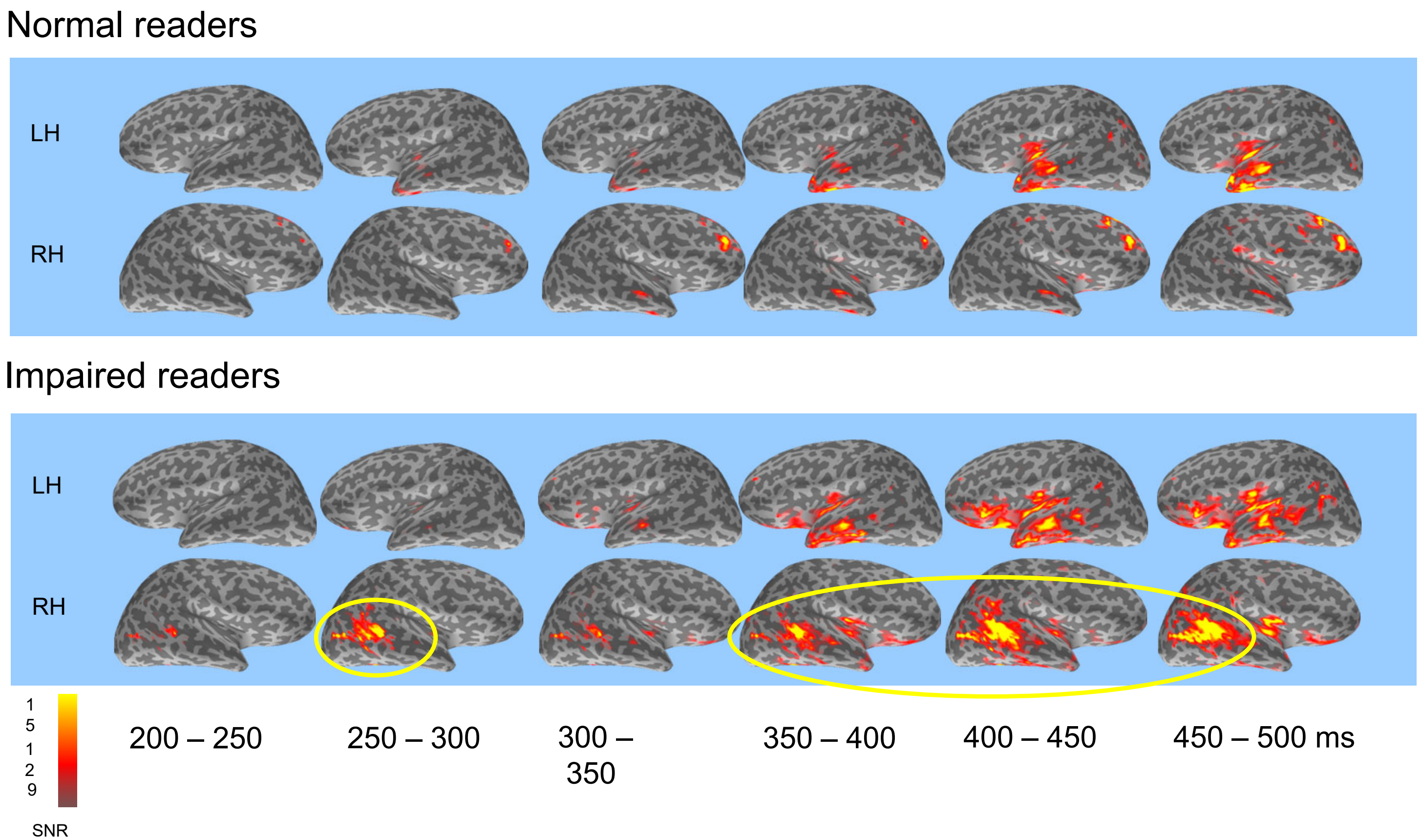
$$\mathbf{W} = \mathbf{W}_{\mathbf{norm}}\mathbf{B}$$

- Problem is highly ill-posed (relative to CT/MRI)
- Alternatives use non-quadratic regularizers, sparse and Bayesian formulations….
- Data-fit error often weighted by inverse noise-covariance



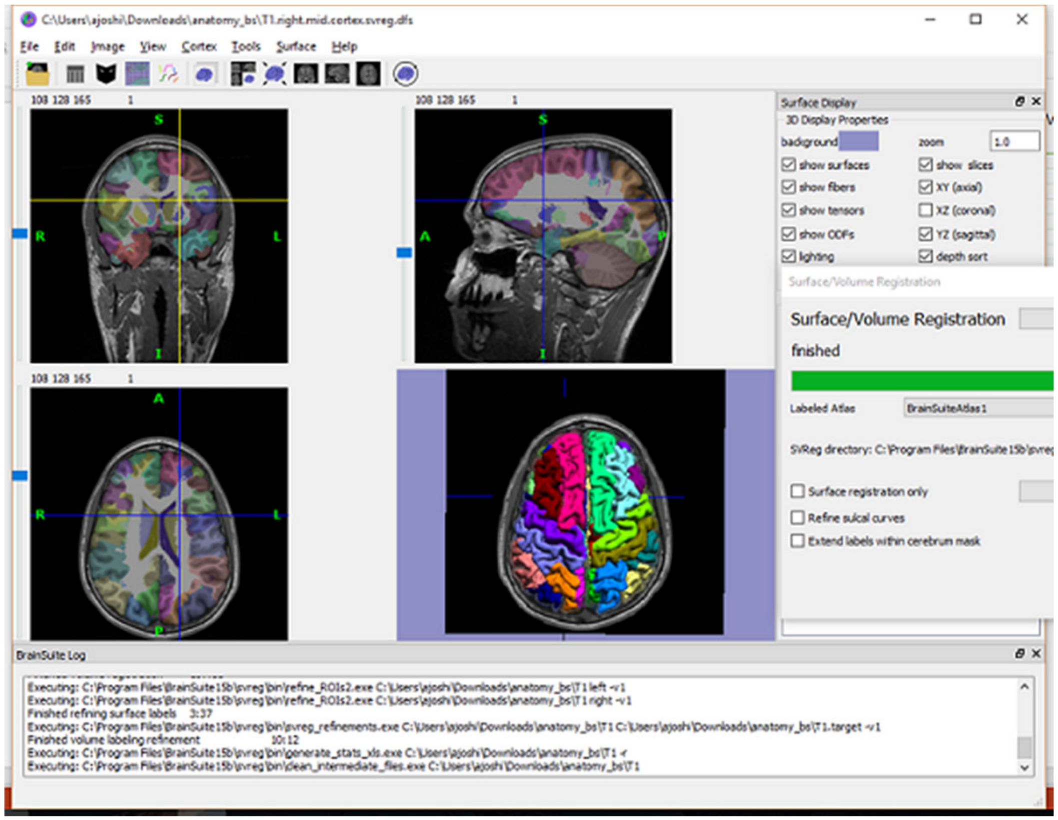
MEG in an auditory oddball task

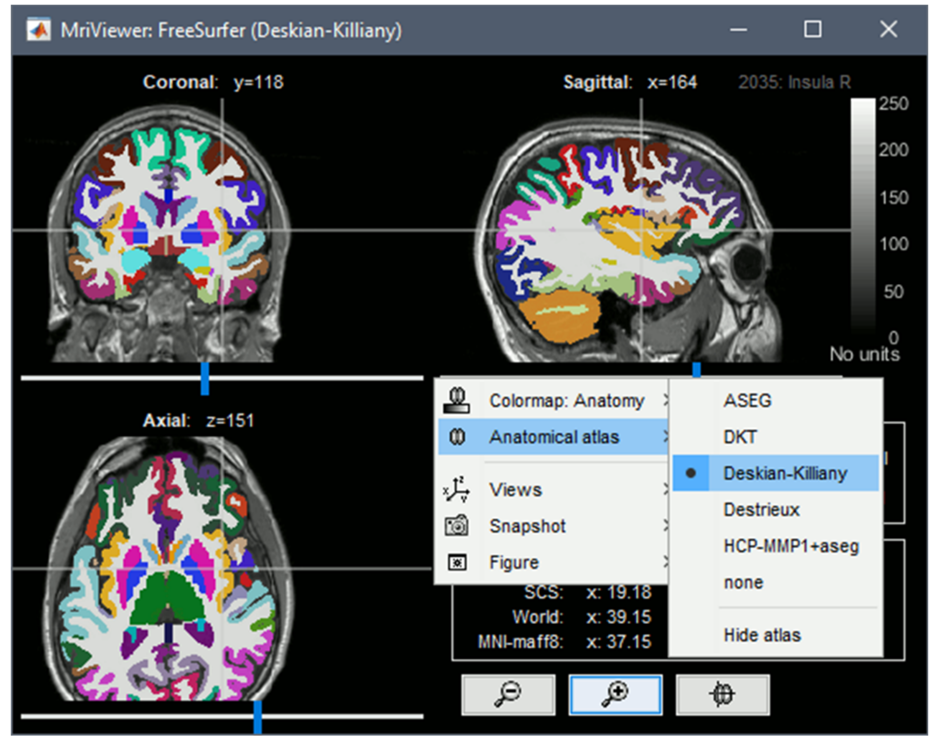
Phonologically similar words (|bøt| vs. |pøt|)
Group analysis of the rare |pøt| in 7 – 13 year olds



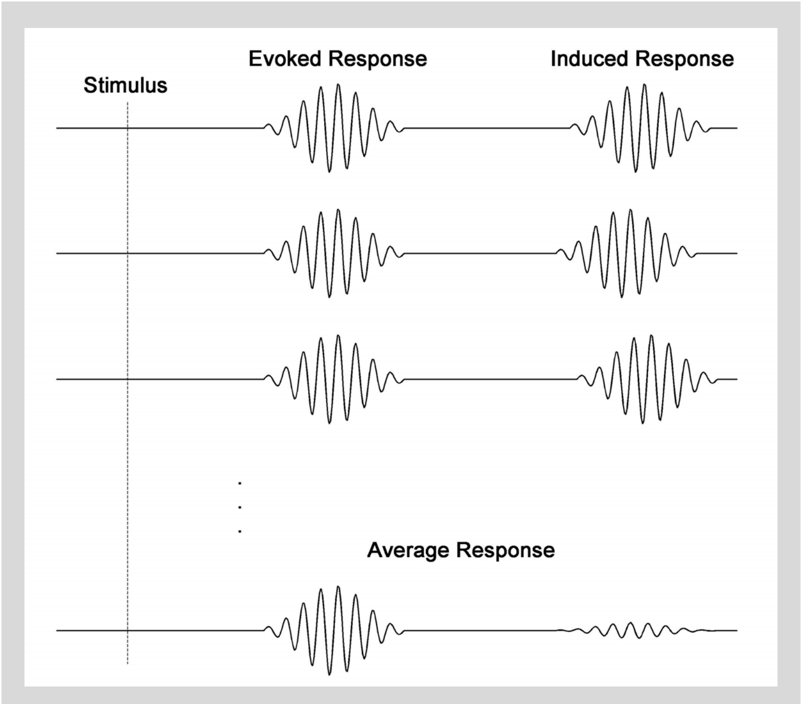
(slide courtesy: Matti Hamalainen)

We can quantify neuronal activity over ROIs in parcellated atlas



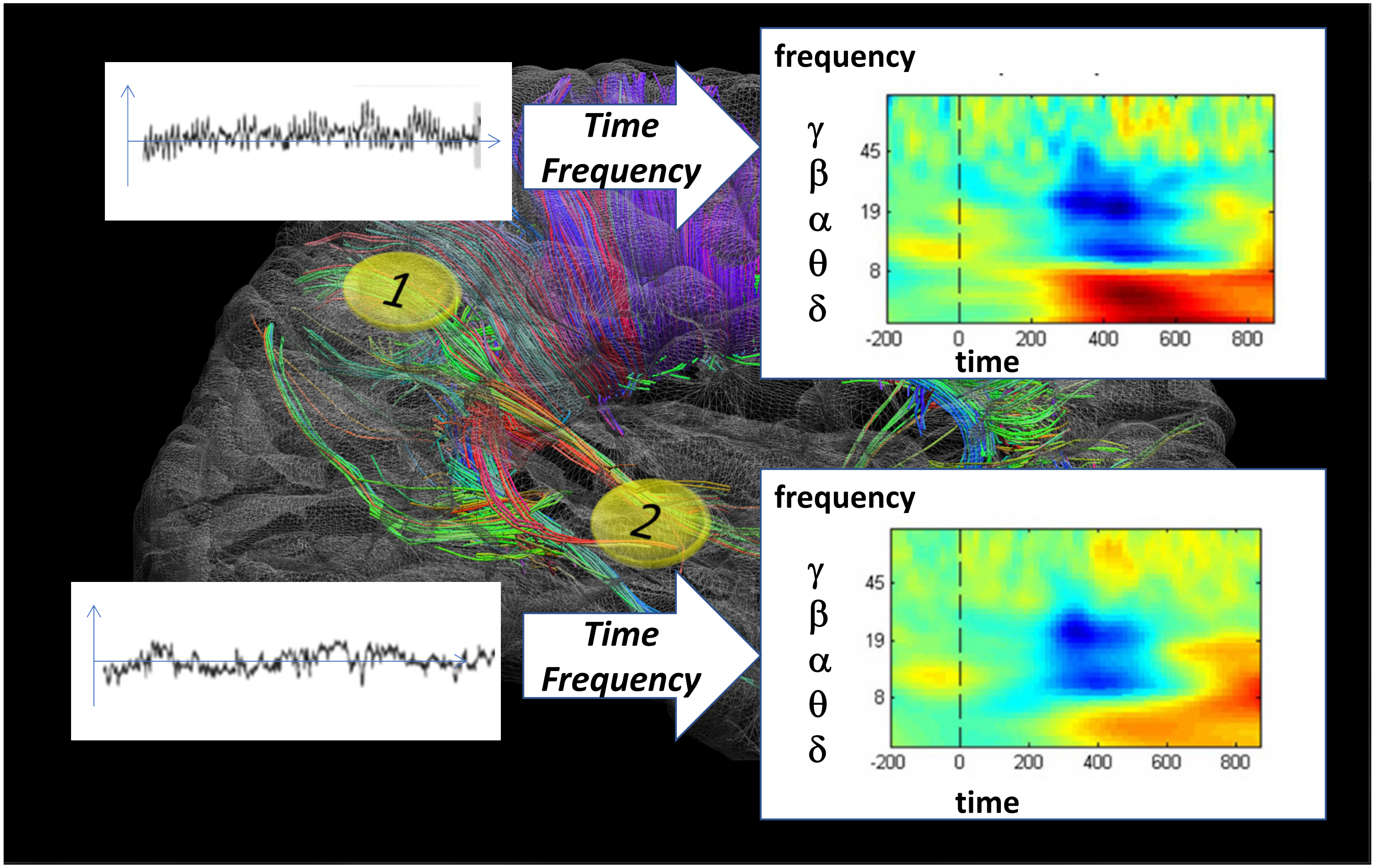


Evoked vs. Induced Response



- Evoked response: Precisely phase locked to the stimulus, averaging increases signal
- Induced response: Variable latency, averaging leads to signal cancelation – instead we average over the time-frequency magnitude

Spatio-temporal complexity



EEG analysis using TF data

Energy Statistic

$$E^{stf} = \left|C^{stf}\right|^2$$

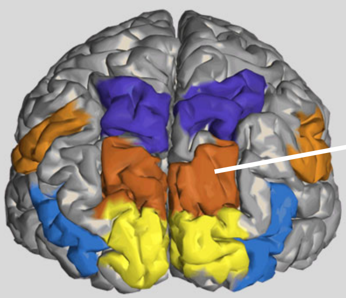
$$E^{STF} = \iiint_{(s,t,f)\in(S,T,F)} \left|C^{stf}\right|^2 ds\,dt\,df$$

$T = [t_1, t_2]$

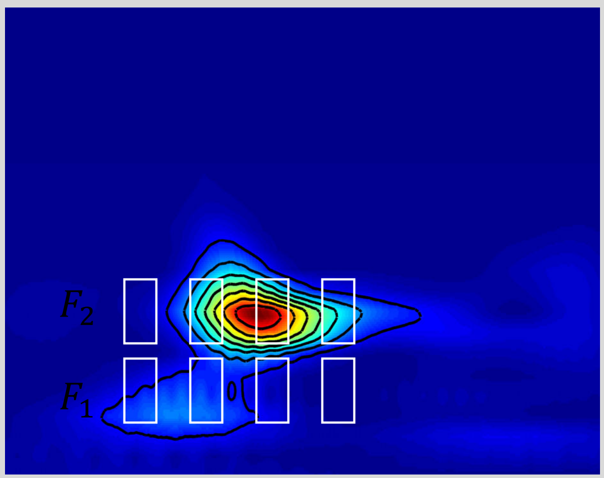
$F = [f_1, f_2]$

$S =$ cortical ROI

Regions of Interest (ROIs)



S_i



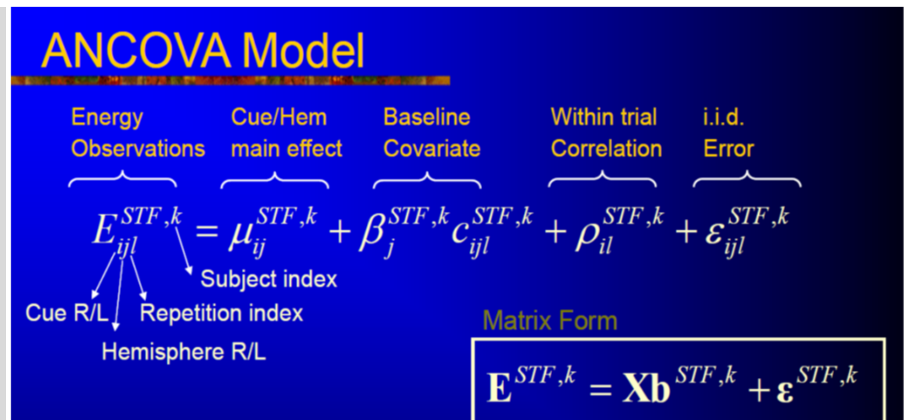
F_2

F_1

T_1 T_2 T_3 T_4

Space

Time-Frequency



μ_{11}	μ_{12}	μ_{21}	μ_{22}	β_1	β_2	ρ_{11}	ρ_{21}	ρ_{12}	ρ_{22}
1						1			
	1					1			
		1					1		
			1				1		
1								1	
	1							1	
		1							1
			1						1

Shift vs. sustain in visual attention task – effects on alpha power

SPL: Superior Parietal Lobe

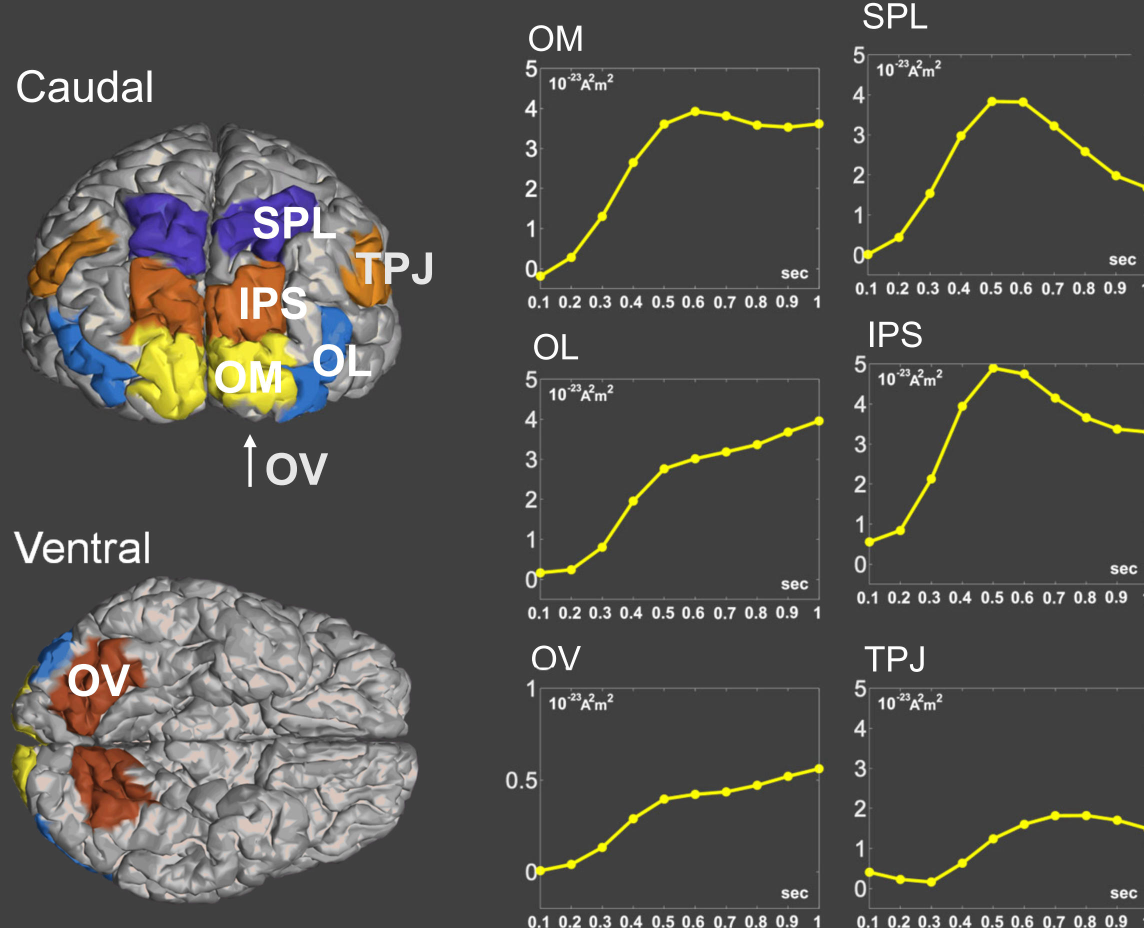
TPJ: Temporal Parietal Junction

IPS: Intra-Parietal Sulcus

OL: Occipital Lateral

OM: Occipital Middle

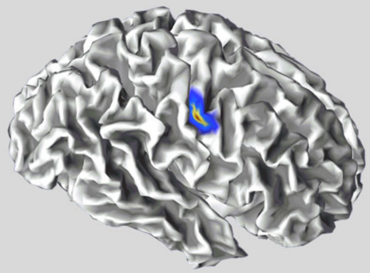
OV: Occipital Ventral



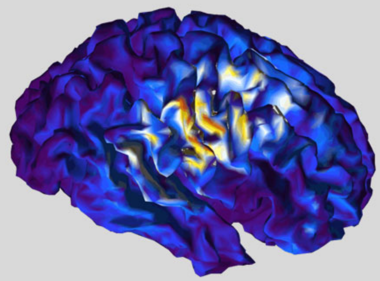
D Pantazis, G Simpson, D. Weber, CL Dale, TE Nichols, RM Leahy (2009) A novel ANCOVA design for analysis of MEG data with application to a visual attention study, Neuroimage. 44(1): 164–174.

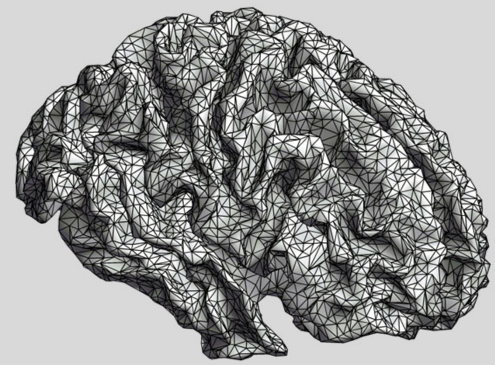
Detecting Statistically Significant Activation: Thresholding

Simulated

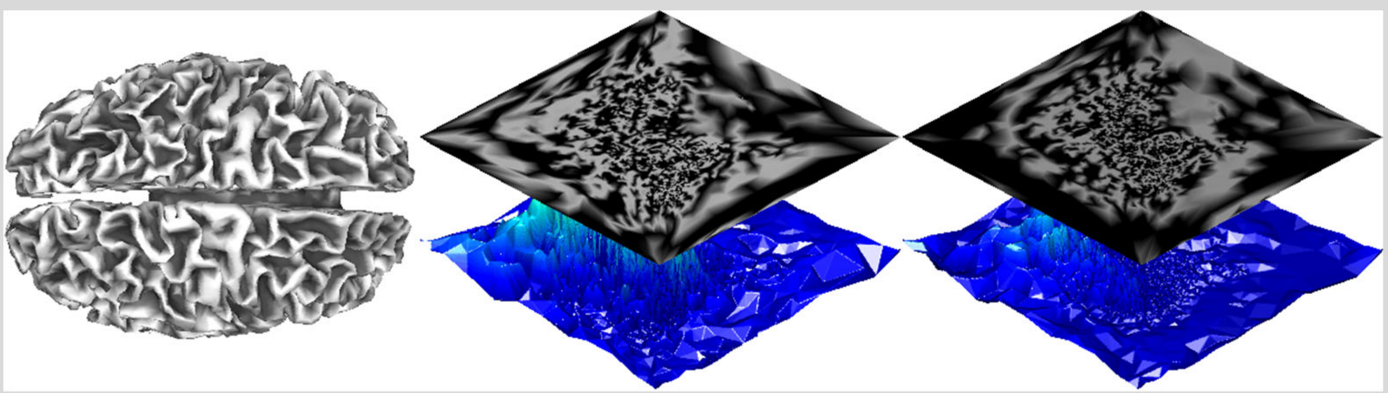


Reconstructed





Thresholded Activity **Right Hemisphere** **Left Hemisphere**



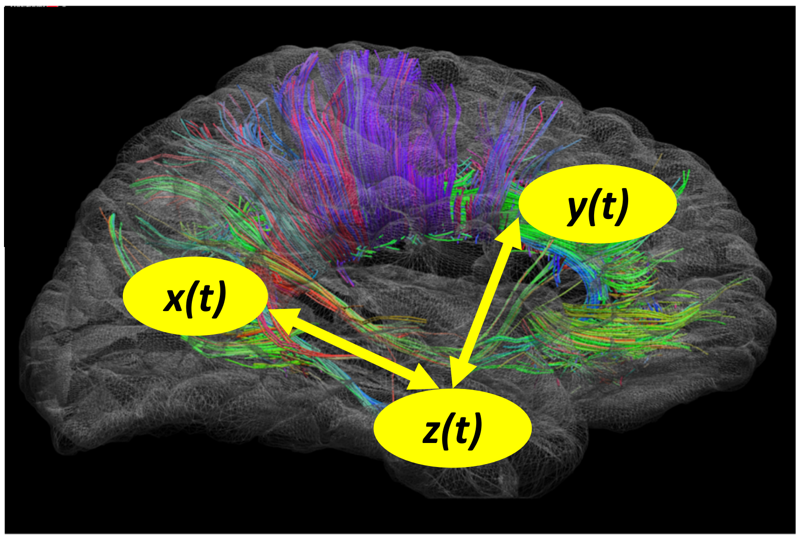
Multiple comparisons

- Control of False Discovery Rate
- Control of Familywise Error Rate

Assumptions

- Parametric model – p-values from distribution
- Nonparametric model: p-values from permutations

Connectivity Analysis



Computer interactions between two or more regions in the brain

PAIRWISE MEASURES	NETWORK MODELS
Correlation	Partial correlation
Coherence	Partial coherence
Phase coupling	Partial phase coupling
Phase/ampl. coupling	???
Canonical correlation	Partial canonical correlation
Granger causality	Directed transfer function
	Independent Components Analysis
	Dynamic causal modeling
	Bayesian networks

Summary

- EEG/MEG can provide unique insights into human brain function through studies of fast temporal dynamics, focal and regional activation, studies of oscillatory activity and connectivity
- Cautionary factors:
  - Limited spatial resolution
  - EEG/MEG signals are complex – mix of event-related and un-related activity
  - Noise: environmental, cardiac, eye-blink, EMG
  - Inter-trial variability