Why and How: MNE

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Outline

PART 1:
What is MNE?
How does it work?

PART 2:
What can we do with the results?
PART 1
What is MNE and how does it work?

What is MNE?
Features of MNE...
Why do we use MNE?
What assumptions are built in?
What do the steps mean?
What is MNE?

What is happening in the brain when we measure a particular set of signals with our MEG sensors?
Why is the question ill-posed?

- The mathematics:
  - 10,000,000,000 neurons
  - 306 sensors
  - Non-unique solutions to this problem alone

- The physics:
  - Impossible to find the true description of the currents inside the head if you measure the electric and magnetic fields from outside, regardless of how many sensors you have. The reason is that infinitely many configurations can result in the exact same MEG/EEG pattern outside the head.
From forward to inverse

**FORWARD MODEL**
- Uses known physics
- Unambiguous

**MEG DATA**
- SIMULATED

**REAL MEG DATA**

**INVERSE MODEL**
- Uses forward model
- ill-posed
What is MNE?

MNE = L2 Minimum Norm Estimate

MNE is one particular method of generating a model of what the brain did to cause a particular MEG signal, given some extra assumptions.
What is MNE?
What's the concept?

A regularized solution to inverse problem of MEG

“L2 norm” is a mathematical operation
(The MCE method uses the L1 norm)

The equation will minimize:
- Difference between the model and the real data
- Amplitude of each current dipole
What is MNE?
In words...

**Make**: model of data look just like real data
ILL POSED because infinite solution set

**Make**: the same thing, with the added “penalty” for large currents in the brain
WELL POSED- only one answer
What is MNE?

In pictures...

ORIGINAL DATA

BEST MODEL: LOOKS LIKE ORIGINAL AND MINIMIZE CURRENT

POSSIBLE MODELS
Features of MNE...

Same answer each time you run it (robust)
Offers linear operators
Assumes small currents in brain
Handles distributed sources
Can use fMRI as prior weights
Makes movies of data in 3D
Places signals on cortical surface
Each time point is computed independently
Why do we use MNE?

- Distributed (i.e. spread out) sources
- Multiple sources (0 to thousands)
- To study evolution of signals (in movies)
- To isolate interesting neural activity from data
- To form 3D (or 4D) views of the data
What assumptions are built in?

- Correct estimate of forward model
- Distributed sources lead to the MEG signal
- Time can be treated with quasi-static physics
- MRI information is accurate
- One inverse per head geometry
- High signal-to-noise ratio
- Small current amplitudes
- Cortical sources
- Noise is temporally stationary
What assumptions are built in?

Correct estimate of forward model

Based on MRI and co-registration – each can introduce error if inaccurate

Several parameters to “pick”

Many methods exist for forward modeling, no one considered “best”

All MNE results based on choice of forward model
What assumptions are built in?

Sources will be interpreted as distributed even if they are not

Example: focal source, computed in two ways:

Found on internet, Fa-Hsuan Lin's poster, HBM 2003
What assumptions are built in?

**Quasi-static approximation to the physics**

Data is sampled “slowly” vs. electromagnetism

Each sample can be solved independently

Spiky or noisy source estimates are “fine” with MNE - no relationship between samples
What assumptions are built in?

- MRI information is assumed to be correct:
  - Brain anatomy
  - Tissue layer geometry
  - MRI-MEG coregistration
- If not, inaccurate results
What assumptions are built in?

One inverse per head geometry

The same inverse model is used on all data

Motion due to pulsation of CSF ignored

Head motion ignored

Assumes no changes in electromagnetic properties of tissue
What assumptions are built in?

High signal to noise ratios assumed

Where this is violated, noise is treated as signal

Noise is not readily discernible from signal after MNE

Goldenholz et al. Human Brain Mapping 2009
What assumptions are built in?

Small current amplitudes
Leads to more distributed results
What assumptions are built in?

Cortical sources only

Ignore other possible source locations

scalp

cerebellum

white matter

heart

eyes
What assumptions are built in?

Noise is temporally stationary

- Noise is presumed to be temporally stationary
- “Noise” is defined with your noise covariance:
  - could be non-brain sensor noise
  - could be brain “resting”
  - could be scalp, heart etc
- Any temporal structure in noise is ignored
What do the steps mean?

MRI-T1
MRI-brain
BEM
SOURCE SPACE
FORWARD MODEL
MRI-aligned
MEG Data
Noise covariance
Filtering/averaging
INVERSE MODEL
PART 2

What can we do with the results

What is my data?
Preprocessing it?
What statistical methods are available?
How can I extract stages of MNE?
Tools, and where to find them....
What is my “data”? You choose...

- Sensor space (MEG signals)
- Source space (dipole signals)
- Norm of source space (magnitude of dipoles)
- RMS of sensors
- RMS of ROI sources
- Mean of ROI sources
- Maximum ROI source
- Whatever you want really
Don't forget to preprocess!

- Filter your data – remove unwanted frequencies
- Artifact rejection (meg,eeg,eog,ecg...)
- SSP – project stationary noise source
- SSS – remove non-brain sources (perhaps)
- Motion correction – part of SSS
- Averaging – assumes underlying brain actions are LTI systems, removes Gaussian noise
- Other options possible... explore...
What statistics are available?

dSPM
Spatiotemporal binning
  Parametric: e.g. T-tests, z-tests, ANOVA
  Non-parametric: e.g. Mann-Whitney
Bootstrapping / jacknifing
Entering the phase and frequency domains
Modeling methods
Speculative methods
dSPM

An F test at each time for each source
Hypothesis:
how likely is this datapoint to have come from the baseline noise? (very unlikely = activation)
Spatiotemporal Binning

Pretend everything from a certain time range is equivalent

And/or: pretend everything from a certain spatial extent is equivalent

Pitfall:

Did you properly account for correlation structure in space and time?

Advantage:

You can use “simple” statistical techniques
Parametric:
e.g. t-tests, z-tests, ANOVA

Dale et al Neuron 2000

Marinkovic et al Neuron 2003
Non-parametric:
e.g. Mann-Whitney

Fig. 3 Region of interest (ROI) analysis of the magnetoencephalography (MEG) data. (a) MEG source waveforms for the left superior temporal gyrus (STG) ROI, obtained from the minimum error estimate (MEE), compared for the congruent (either phonologically similar or phonologically dissimilar)-congruent conditions and averaged across all participants in the good (top) and poor (bottom) reader groups. The shading indicates the 200–300 ms time range where a significant interaction effect was found. Time (ms) corresponds to the onset of the critical final word in a sentence. The location of the left STG ROI is shown on an inflated cortical surface rendering of one participant. (b) Magnitude of the group-averaged MNE activation in the left STG.
Bootstrapping/Jacknifing

Darvas et al. Neuroimage 2004

Chait et al. Brain Research 2008
Phase/frequency domain

Lachaux et al. HBM 1999
Modeling methods

Keibel et al Neuroimage 2004
Speculative methods

There are other weird ideas out there
• Some of my untested ideas are found online:
  – Nonparametric statistics
  – Group dSPM
  – MANOVA with repeated measures

www.nmr.mgh.harvard.edu/~daniel Click on presentations click on stats on ROI
How to extract stages of MNE?

Several things:
FREESURFER TOOLS (freesurfer wiki)
MNE GUI (MNE manual ch7)
MNE Conversion utilities (MNE manual ch9)
MNE Matlab toolbox (MNE manual ch10)
Some example uses...

• Quality checks on data:
  – Is the noise covariance structure reasonable?
  – Do the BEMs follow anatomy properly?
  – Does the source space include impossible locations or strange geometries?
  – SNR of the forward model?
  – Effect of fMRI priors on inverse model
  – SVD of inverse – effective dimension?
Some example uses

• Spatial resampling:
  – If head position shifted
  – between runs, sessions or even MEG systems
  – Data can be placed properly in source space
  – Averaging might make sense in source space (?)

• Averaging inverse models
  – May provide some sort of motion correction?
More to explore...

**MNE**

- Matti's excellent talks on MNE and dipoles
  http://www.martinos.org/meg/talks.php
- Hamalainen et al Rev Mod Physics 1993
- Dale and Sereno J Cog Neurosci 1993

- dSPM paper
  - Dale et al Neuron 2000

- My “Stats on ROI” talk:
  - www.nmr.mgh.harvard.edu/~daniel/links/presentation