Donders Institute
for Brain, Cognition and Behaviour

Beamforming
Reconstructing more than blobs

Robert Oostenveld

Donders Institute for Brain, Cognition and Behaviour
Radboud University Nijmegen, The Netherlands

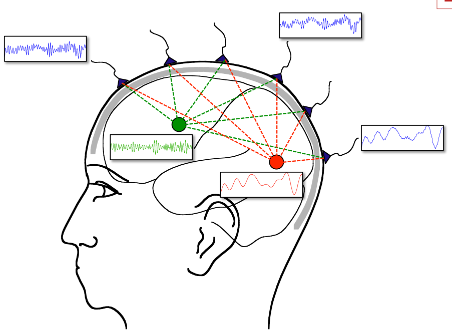
NatMEG, Karolinska Institutet, Stockholm

Radboud University Nijmegen

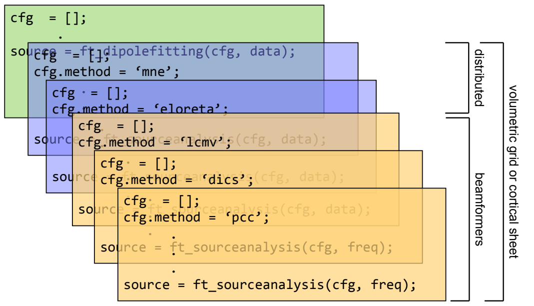
Talk outline

- Recap source reconstruction methods
- Similarities between methods
- Linear mixing and unmixing
- Beamforming in detail
- Computing and using spatial filters
- Suggested further reading

Linear superposition of source activity



Source reconstruction in FieldTrip



Data model

$M = G_1X_1 + G_2X_2 + \ldots + G_nX_n + \text{noise}$

$M = G\ X\ + \text{noise}$

WARNING: the letters will be used differently in later slides

here **G** = gain matrix, **X** = source activity, **M** = measurement

later **H** = gain matrix, **S** = source activity, **X** = measurement

Data model for sequential dipole fitting

$M = G_1X_1 + G_2X_2 + \ldots + G_nX_n + \text{noise}$

n is typically small

$(M - G_1X_1 \qquad)$ = residual

measured data — model data

$X' = W\ M$, where $W = G^T (G\ G^T)^{-1}$

Data model for distributed source estimates

$M = G_1X_1 + G_2X_2 + \ldots + G_nX_n$ + noise

n is typically large (> # channels)

$M = (G_1X_1 + G_2X_2 + \ldots + G_nX_n)$ + noise

$M = G\,X$ + noise

$X' = W\,M$, where W ensures $\min_X \{\| M - G \cdot X \|^2 + \lambda \cdot \| X \|^2\}$

Data model for spatial filtering

$M = G_1X_1 + G_2X_2 + \ldots + G_nX_n$ + noise

any number of n

$M = (G_1X_1 + G_2X_2 + \ldots) + G_nX_n$ + (noise)

$X'_n = W_n\,M$, where $W^T = [G_n^T C_M^{-1} G_n]^{-1} G_n^T C_M^{-1}$

Data model to estimate source timeseries

$M = G_1X_1 + G_2X_2 + \ldots + G_nX_n$ + noise

few sources → $X'(t) = W\,M(t)$
distributed sources →
one at a time →

W ← dipole fitting
minimum norm estimate
beamforming

Data model to estimate spectral representations

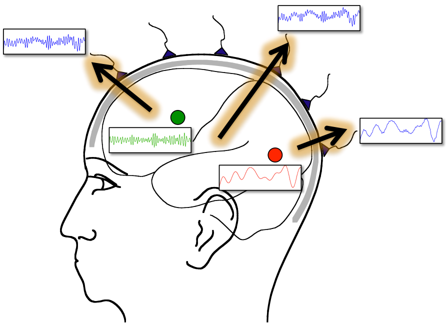
$$M = G_1X_1 + G_2X_2 + \dots + G_nX_n + \text{noise}$$

few sources
distributed sources
one at a time

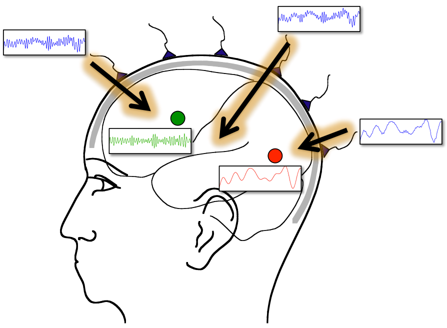
$$X'(f) = W\,M(f)$$

dipole fitting
minimum norm estimate
beamforming

Linear mixing and unmixing



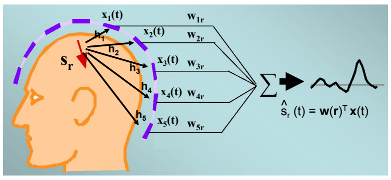
Linear mixing and unmixing



Beamformer: linear unmixing

What is the activity of a source **s**, at a location **r**, given the data **x**?

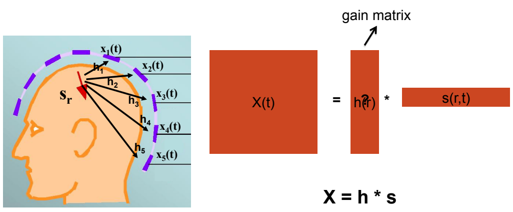
We estimate **s** with a spatial filter **w**



Beamformer ingredients: forward model

How is a source ‘seen’ by the sensor-array?

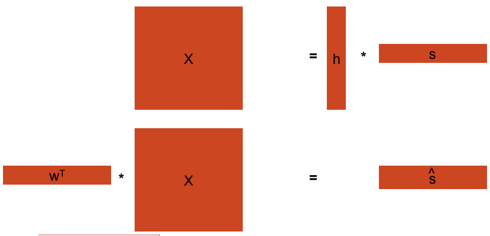
Given a source **s** at location **r** (and orientation η), what is the data **x**?



X = h * s

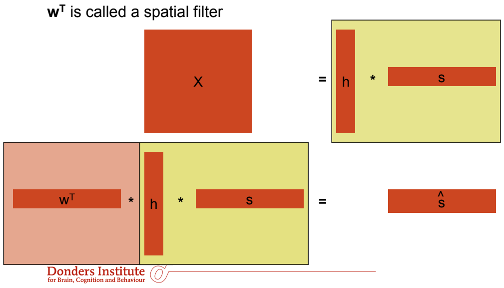
Beamformer: the question revisited

What is the activity of a source **s**, at a location **r**, given the data **X**?
We know how to get from source to data: **X = h * s**
We want to go from data to source: **w^T * X = s ^**
w^T is called a spatial filter



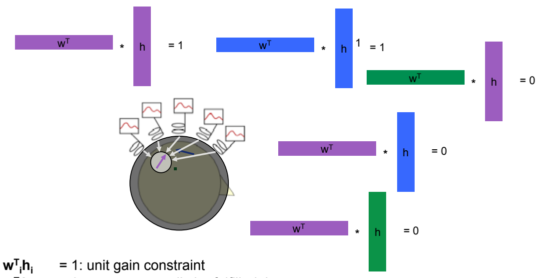
Beamformer: the question revisited

What is the activity of a source **s**, at a location **r**, given the data **X**?
We know how to get from source to data: **X = h * s**
We want to go from data to source: $\mathbf{w}^T * \mathbf{X} = \hat{\mathbf{s}}$
$\mathbf{w}^T$ is called a spatial filter



Donders Institute for Brain, Cognition and Behaviour

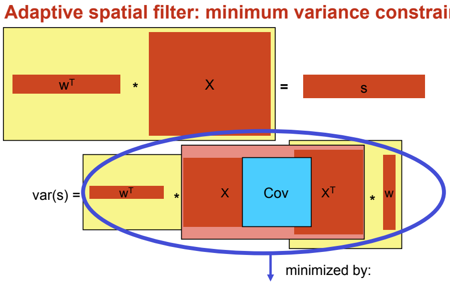
What would we like the spatial filter to do?



$\mathbf{w}^T_i \mathbf{h}_i$ = 1: unit gain constraint
$\mathbf{w}^T_i \mathbf{h}_k$ = 0: cannot generally be fulfilled, hence we minimize the variance of the filter output

Donders Institute for Brain, Cognition and Behaviour

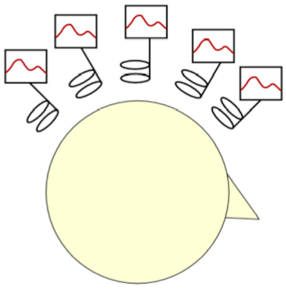
Adaptive spatial filter: minimum variance constraint



$$\mathbf{w}^T = [\mathbf{h}^T \mathbf{Cov}^{-1} \mathbf{h}]^{-1} \mathbf{h}^T \mathbf{Cov}^{-1}$$

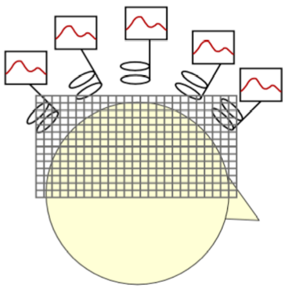
Donders Institute for Brain, Cognition and Behaviour

Beamformers: the concept



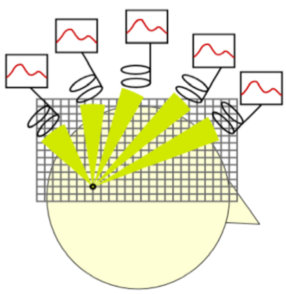
Donders Institute for Brain, Cognition and Behaviour

Beamformers: the concept



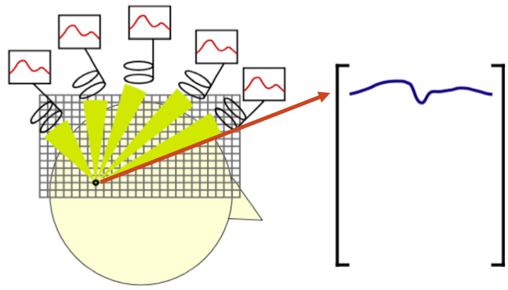
Donders Institute for Brain, Cognition and Behaviour

Beamformers: the concept

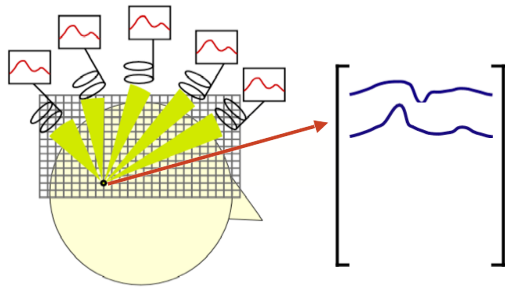


Donders Institute for Brain, Cognition and Behaviour

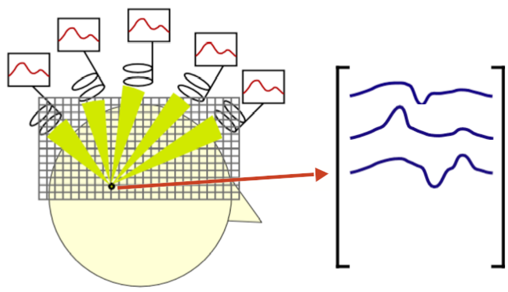
Beamformers: the concept



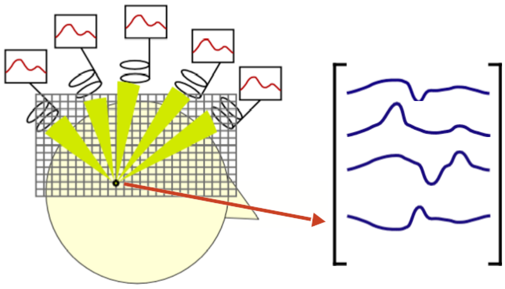
Beamformers: the concept



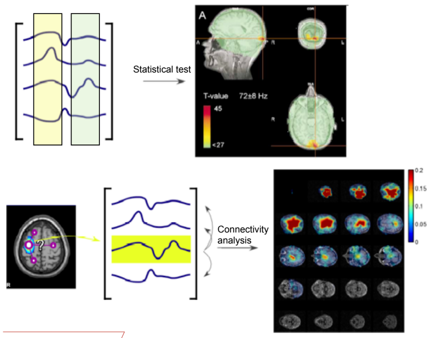
Beamformers: the concept



Beamformers: the concept



And then: creating the blobs ...



Donders Institute for Brain, Cognition and Behaviour

Summary

- Recap source reconstruction methods
- Similarities between methods
- Linear mixing and unmixing
- Beamforming in detail
- Computing and using spatial filters

Donders Institute for Brain, Cognition and Behaviour

Suggested further reading

Tutorials

http://fieldtrip.fcdonders.nl/tutorial/headmodel_meg
http://fieldtrip.fcdonders.nl/tutorial/headmodel_eeg
http://fieldtrip.fcdonders.nl/tutorial/natmeg/dipolefitting
http://fieldtrip.fcdonders.nl/tutorial/minimumnormestimate
http://fieldtrip.fcdonders.nl/tutorial/beamformer

http://fieldtrip.fcdonders.nl/example/create_single-subject_grids_in_individual_head_space_that_are_all_aligned_in_mni_space

Papers

http://fieldtrip.fcdonders.nl/references_to_review_papers_and_teaching_material

Donders Institute for Brain, Cognition and Behaviour