# Assessment of connectivity with MEG

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# Outline

- Crash course on source modelling
- MEG Source estimation in the HCP
- Estimation of connectivity from source-reconstructed MEG data
- Connectivity estimation using spectrally resolved connectivity metrics
- MEG Connectivity estimation in the HCP
- Some notes on parcellations

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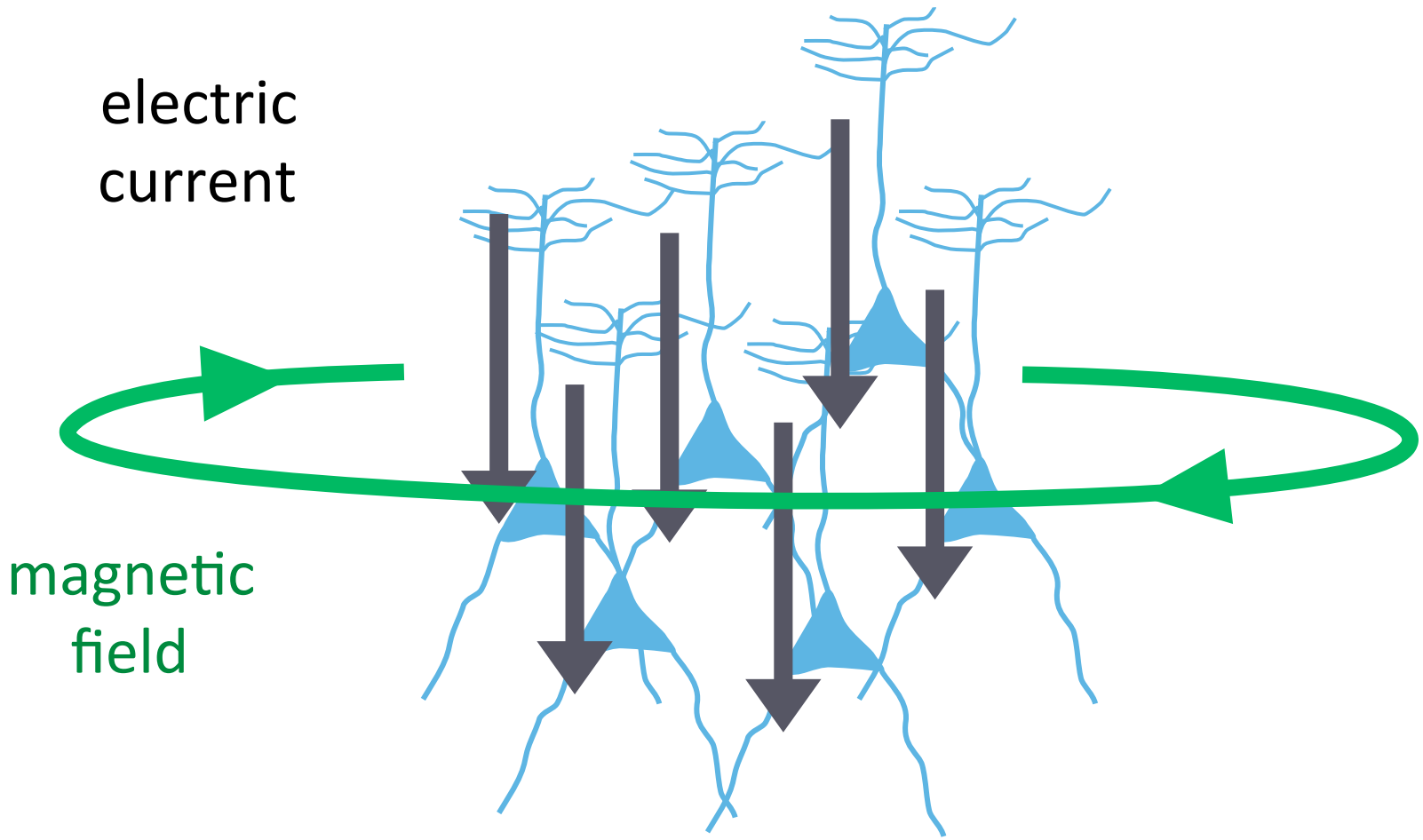
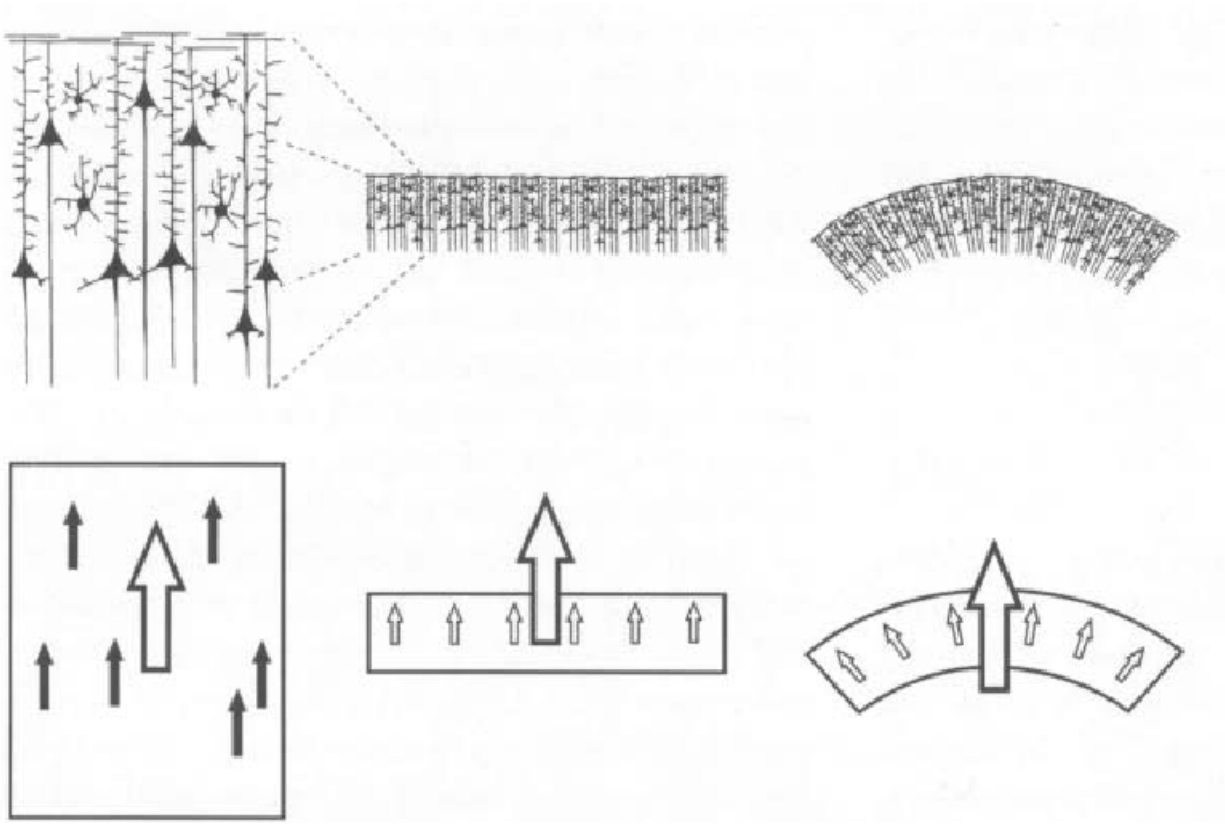
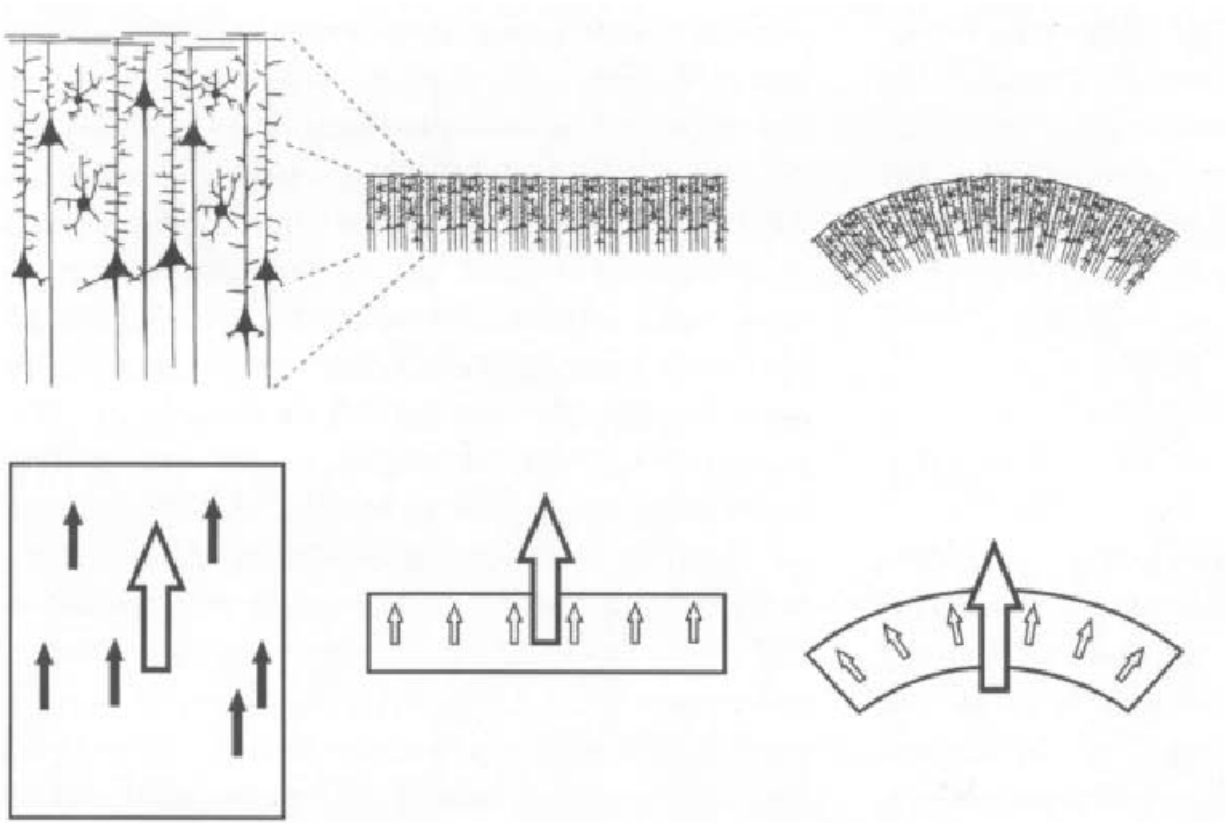
# What produces the electric current and magnetic field



# Equivalent current dipoles



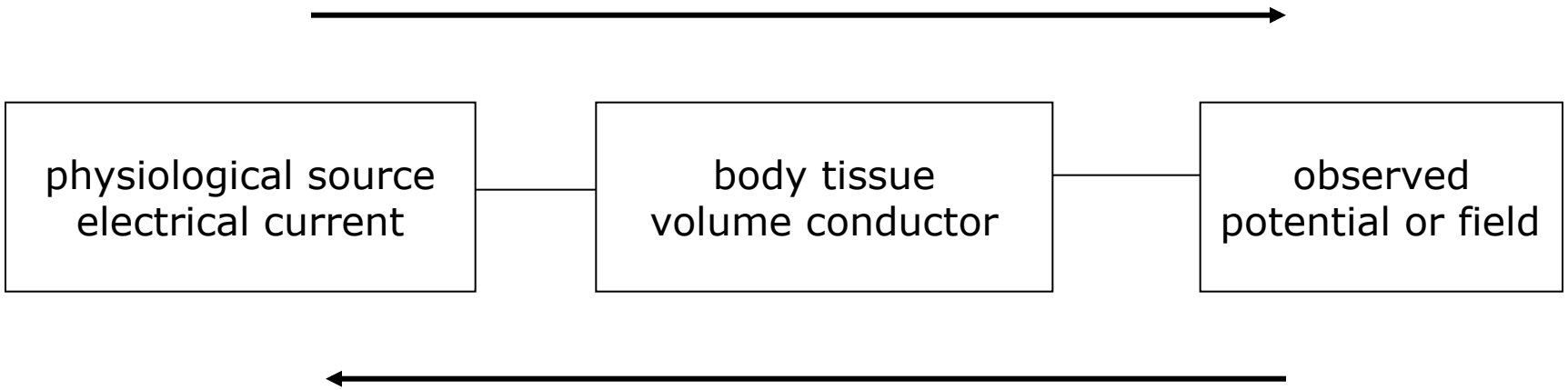
# Equivalent current dipoles



Note: dipole moment is a vectorial quantity

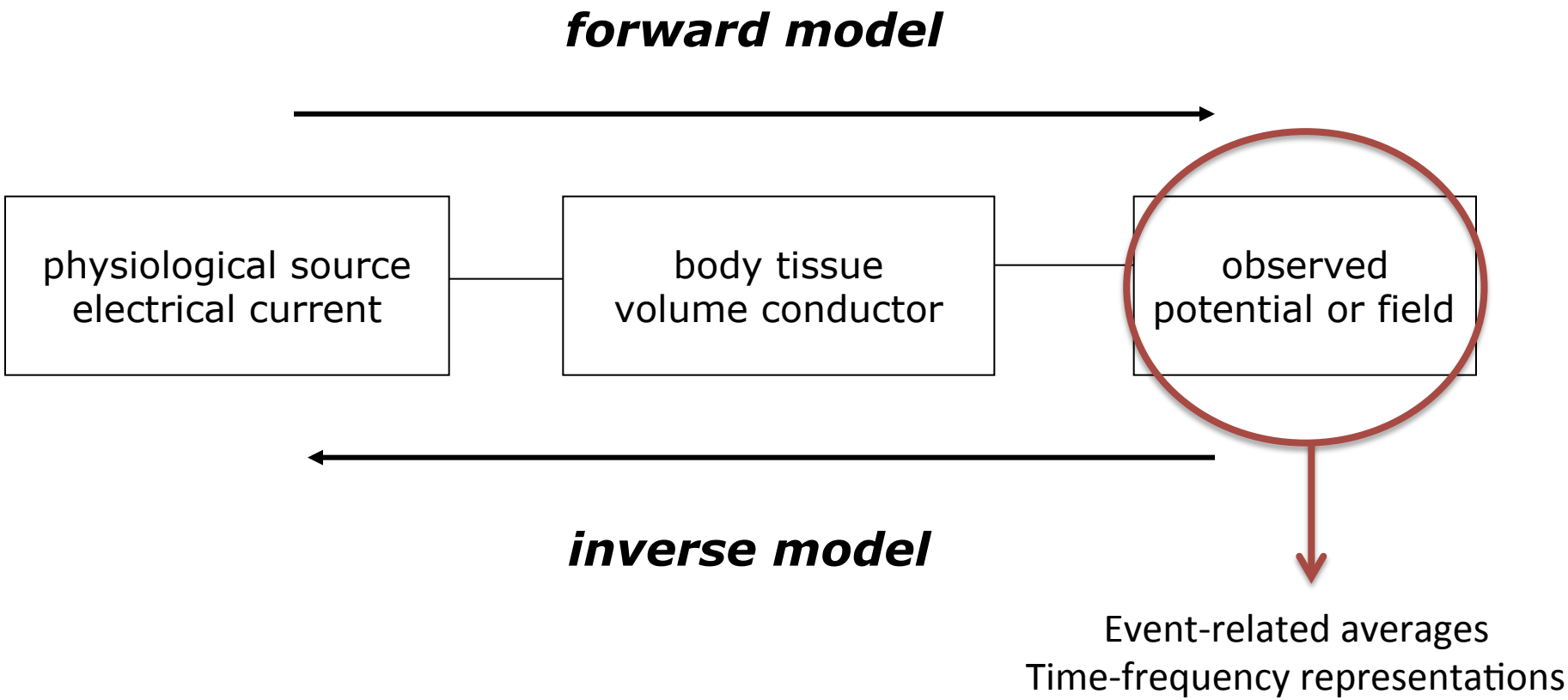
# Source analysis: overview

***forward model***




***inverse model***

# Source analysis: overview



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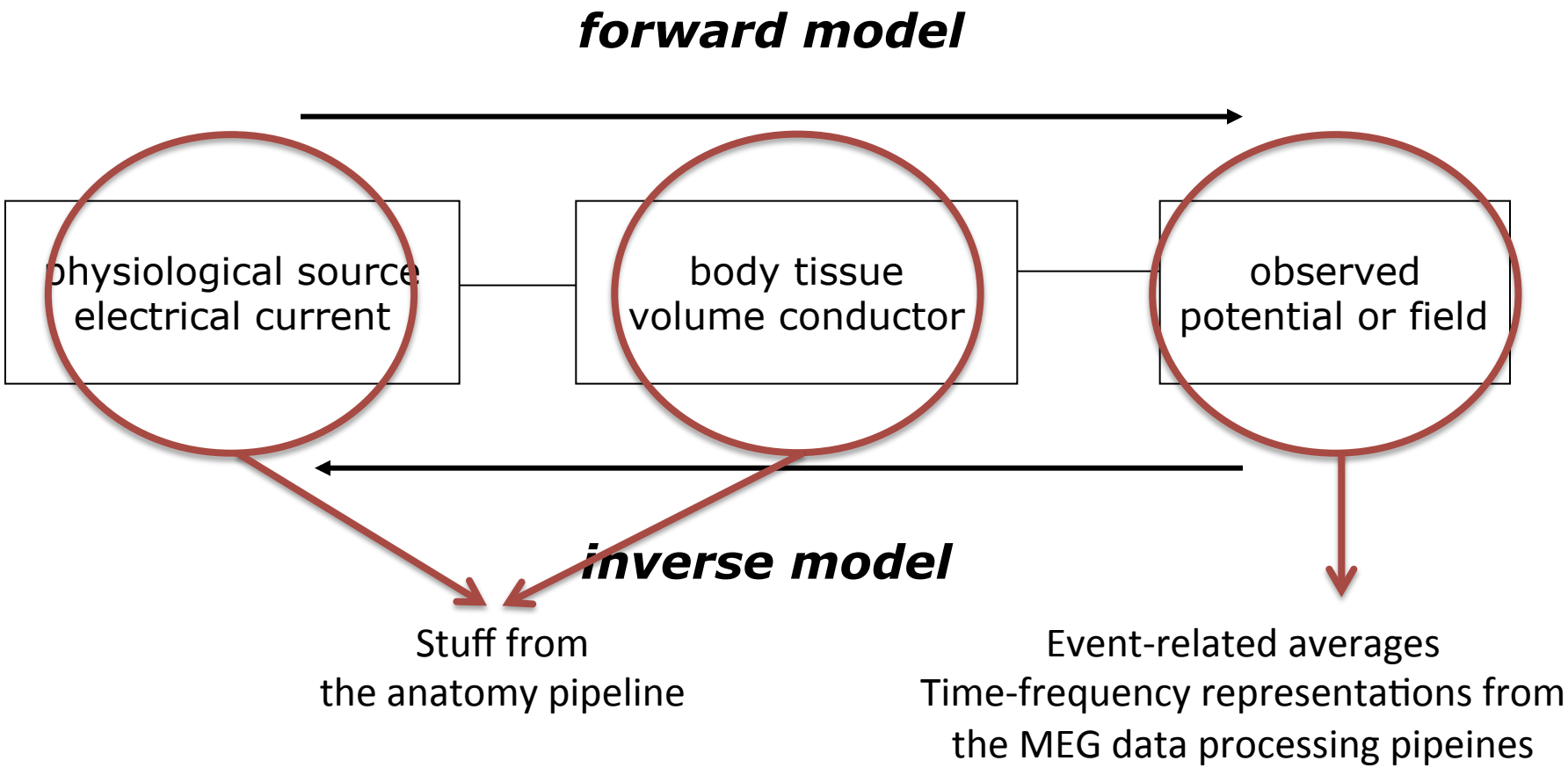


# Stuff from the anatomy pipeline

- Volume conduction model of the head needed to model the volume currents associated the primary neuronal currents

- Cortical sheet based source model (8004 vertices) defines the locations at which the activity is going to be estimated

- Coregistration information
  needed to tie everything together in space

# Stuff from the anatomy pipeline

- Volume conduction model of the head needed to model the volume currents associated the primary neuronal currents

- Mesh describing the inner surface of the skull

# Stuff from the anatomy pipeline

- Cortical sheet based source model (8004 vertices) defines the locations at which the activity is going to be estimated

- Based on the surface-registered 32k midthickness meshes

# Stuff from the anatomy pipeline

- Coregistration information
  needed to tie everything together in space

- Necessary evil due to different conventions in coordinate systems

- MEG employs external landmarks-based ALS

- MRI employs brain anatomy based RAS

- ASCII text file with 4x4 Affine matrices

# Source analysis: overview

***forward model***

$$X = l_1 s_1 + l_2 s_2 + \ldots + l_n s_n + \text{noise}$$

***inverse model***

# Source analysis: overview

***forward model***

$$X = l_1 s_1 + l_2 s_2 + \ldots + l_n s_n + \text{noise}$$

$$X = LS + \text{noise}$$

***inverse model***

# Source analysis: overview

***forward model***

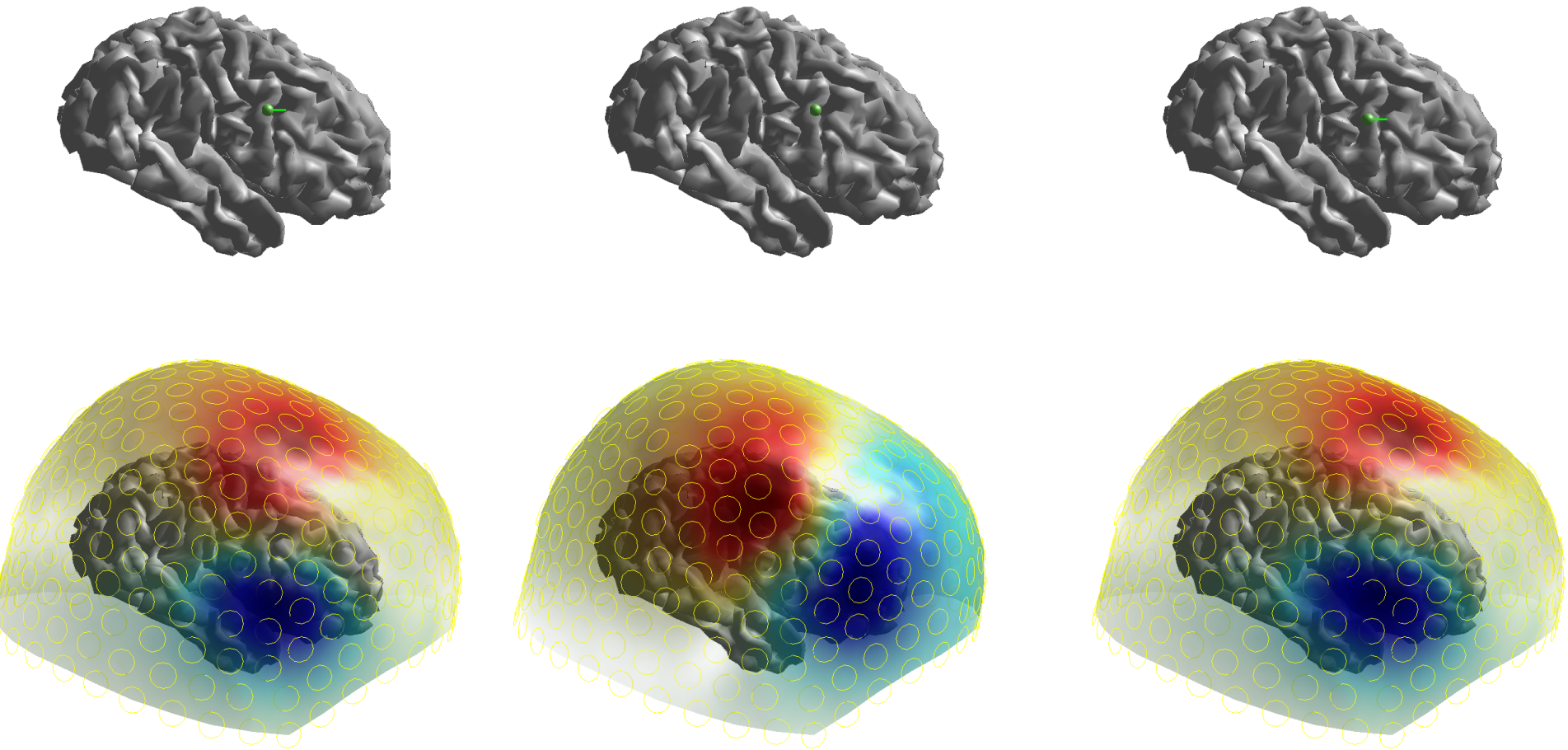
$$X = l_1 s_1 + l_2 s_2 + \ldots + l_n s_n + \text{noise}$$

$$X = LS + \text{noise}$$

Leadfield matrix

***inverse model***

# Leadfields represent ‘spatial fingerprints’



# Source analysis: overview

***forward model***

$$X = l_1 s_1 + l_2 s_2 + \ldots + l_n s_n + \text{noise}$$

$$X = LS + \text{noise}$$

***inverse model***

$$\hat{S} = W^T X$$

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# MEG source estimation in the HCP

- Beamforming:
  scan a set of pre-specified dipole locations, and create a spatial filter with:
  $w^T=(l^TC^{-1}l)^{-1}l^TC^{-1}$

- Distributed source modelling with a weighted minimum norm constraint:
  $W^T=RL^T(LRL^T+\lambda N)^{-1}$

# MEG source estimation in the HCP

- Beamforming:
  tMEG data + rMEG data

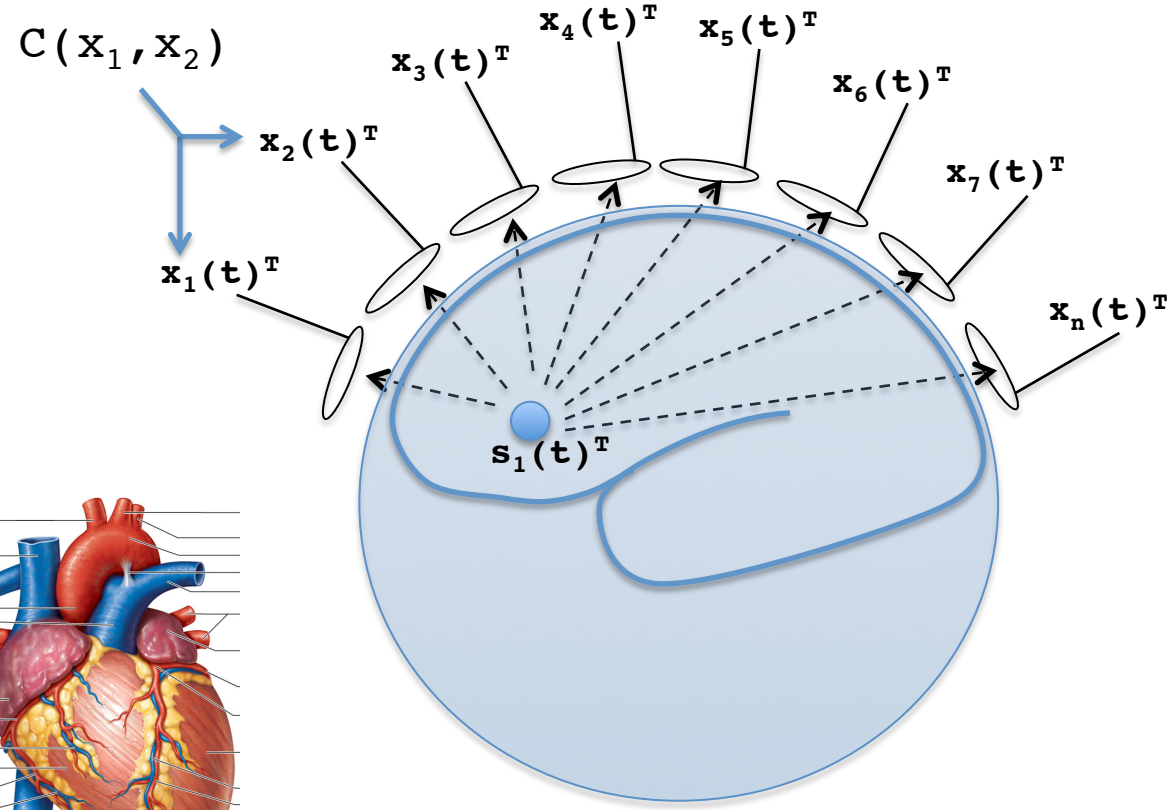
- Distributed source modelling with a weighted minimum norm constraint:
  rMEG data

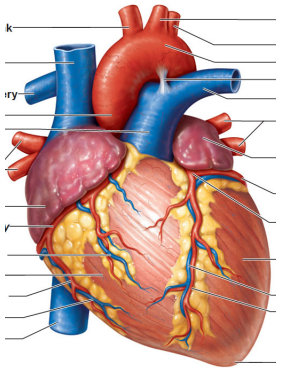
# MEG source estimation in the HCP

- Purpose 1: spatially align MEG data to the other modalities (approximate)
- Purpose 2: achieve ‘unmixing’ so that connectivity estimation makes sense

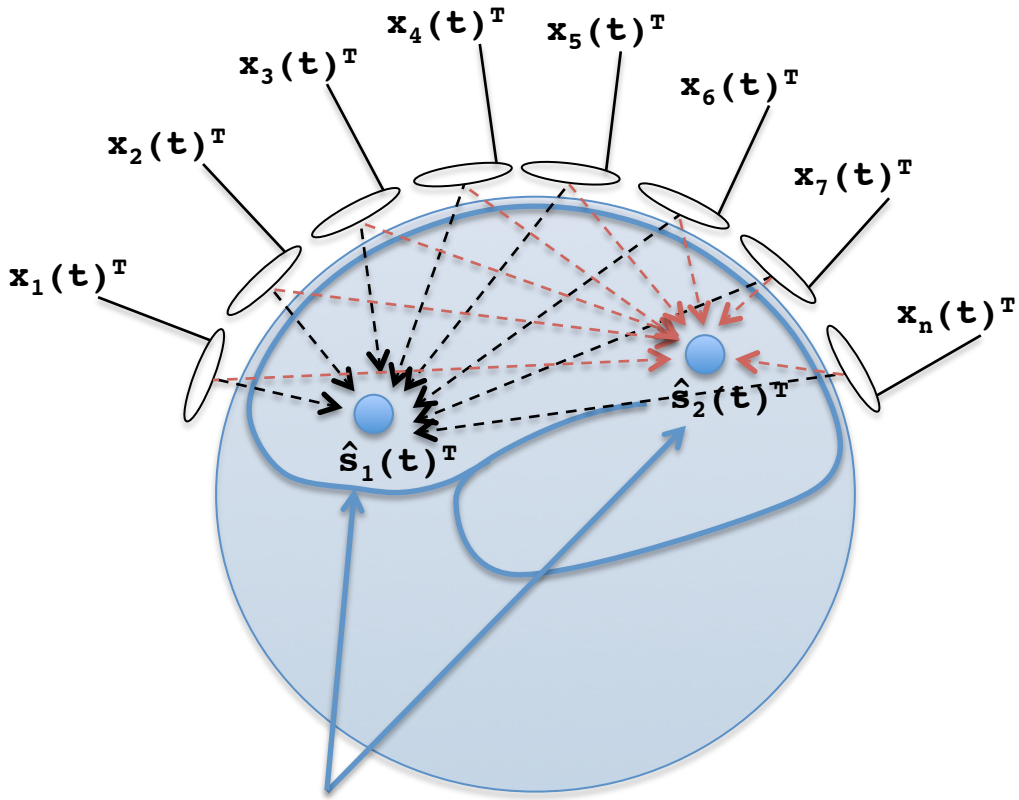
# Motivation for ‘unmixing’

Confounded interpretation of channel level connectivity estimates



# Source-level connectivity: better idea




$C(\hat{s}_1, \hat{s}_2)$

Note: there will still be signal leakage

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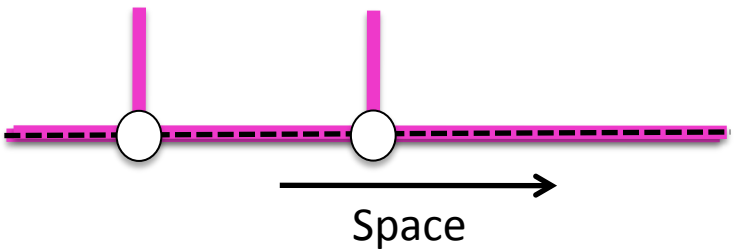
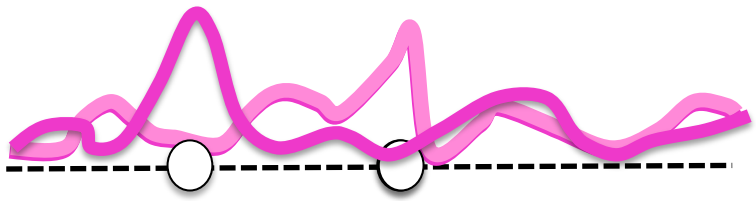
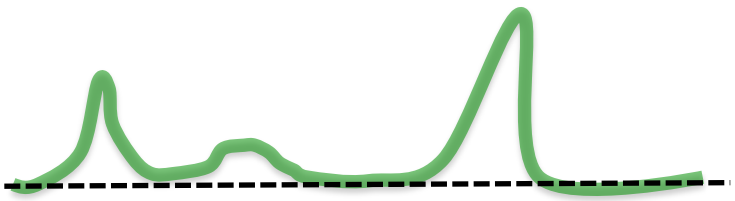
# Spatial filters are inherently blurry

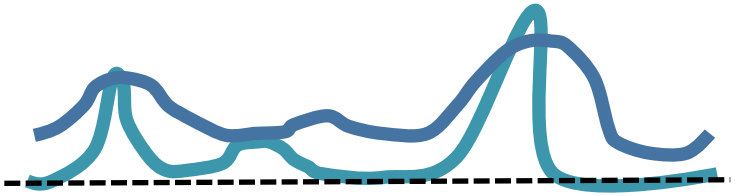


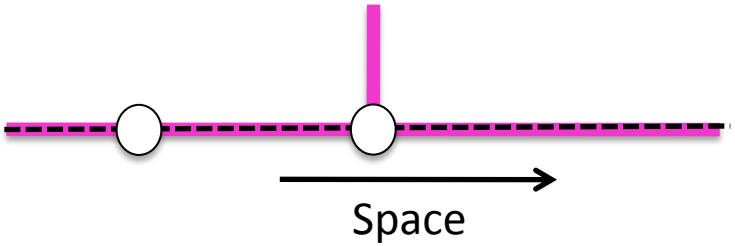
True source activity

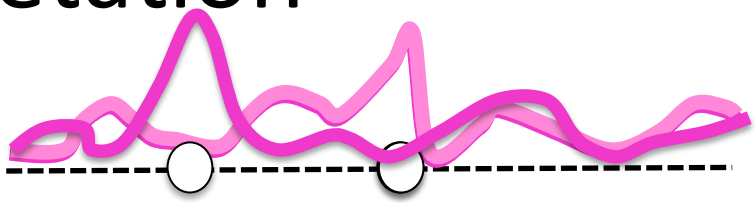


Estimated source activity



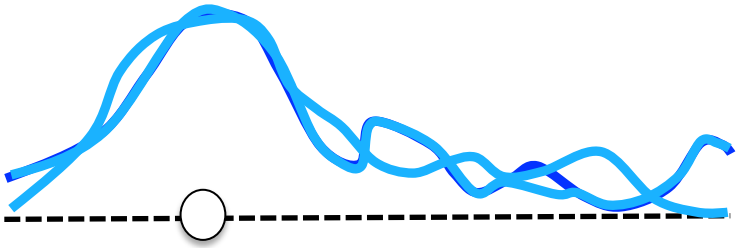
# Take blurriness into account in interpretation



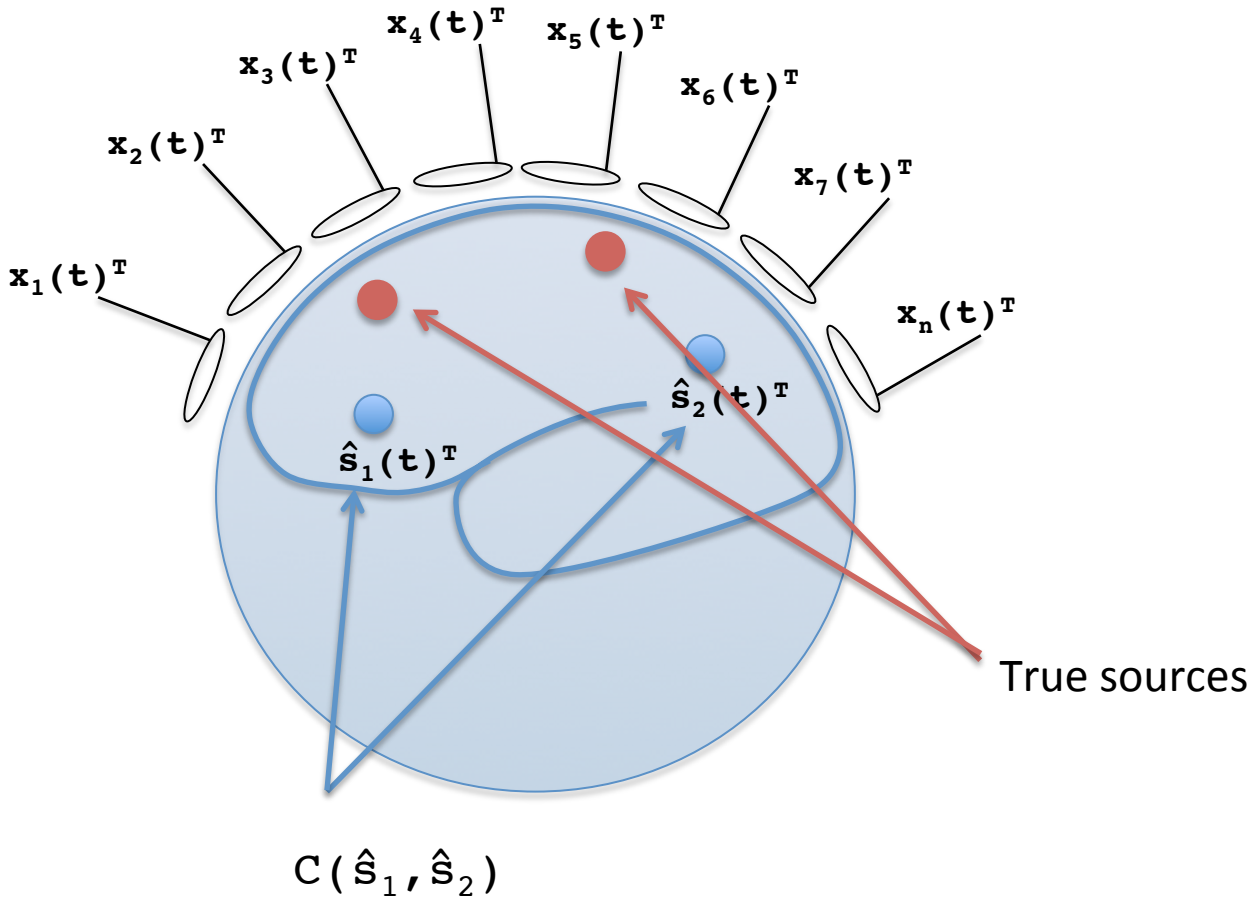



True source connectivity

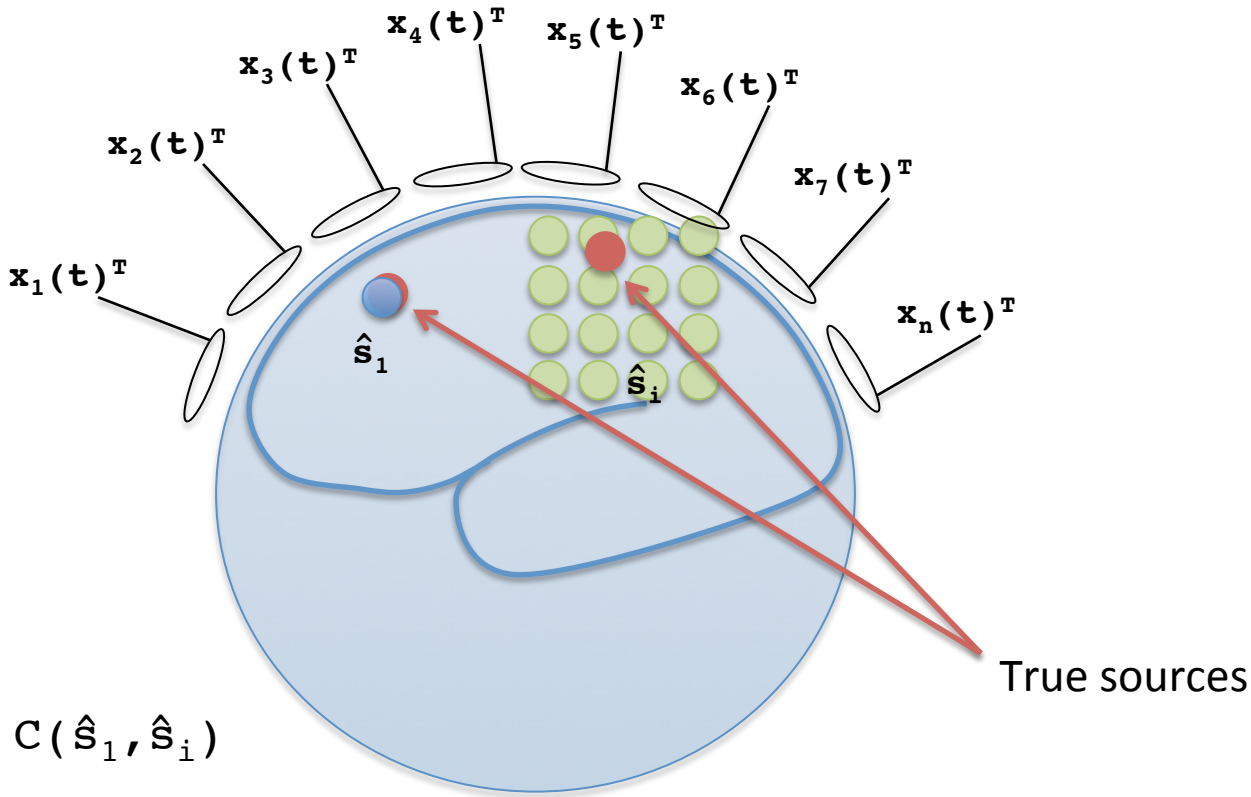
Estimated source conn



# Source-level connectivity: where to look?

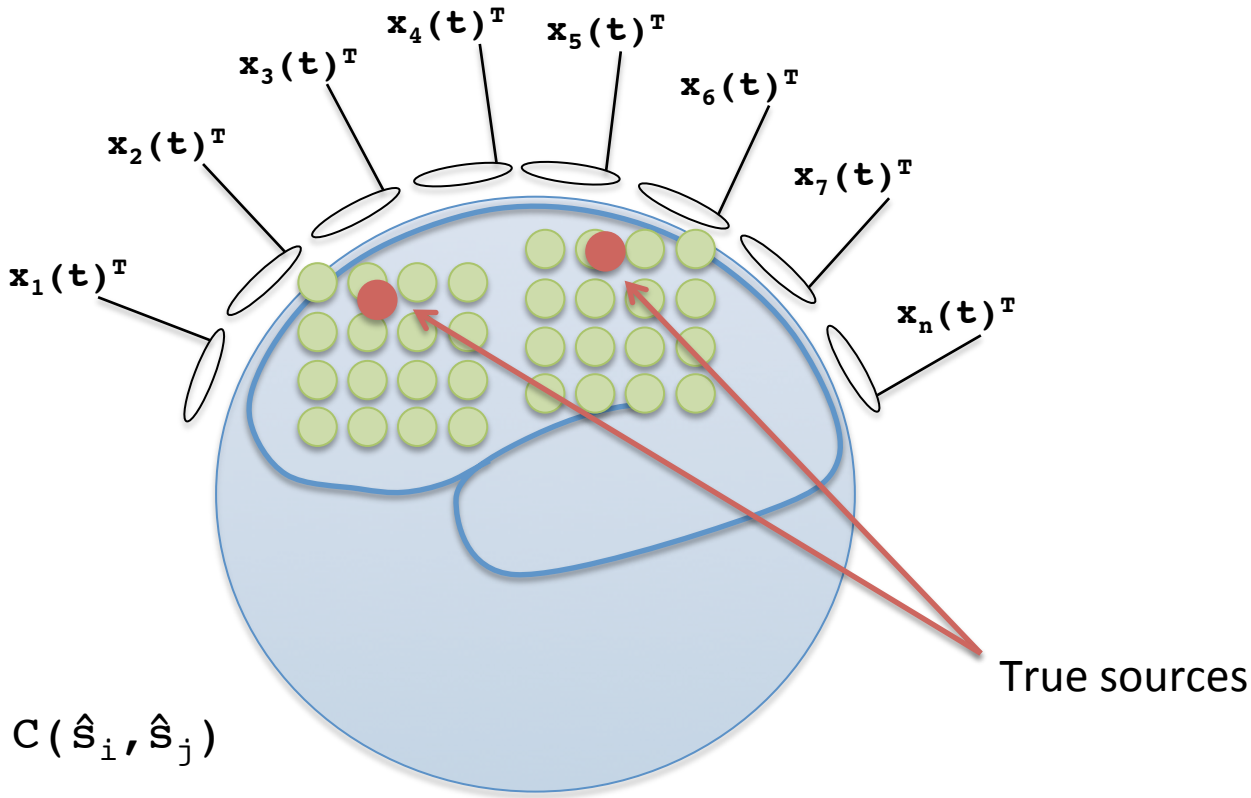


# Source-level connectivity: start looking from locations that make sense a priori (seed-based approach)




- tMEG setting: use functionally defined seeds, e.g.
  - Sensorimotor 'voxel' showing highest coherence to reference EMG signal
  - Fusiform face area 'voxel' showing selective sensitivity to face stimuli
- rMEG setting: use fMRI RSN-based seeds

# Source-level connectivity: all-to-all approach




- Allows for investigation of full spatial structure
- Some part of the spatial structure reflect spurious connectivity

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# Connectivity metrics

- Many a metric on the market
- Functional versus effective connectivity
- Time domain versus frequency domain
- Frequency domain: using amplitude information versus using phase (+amplitude) information

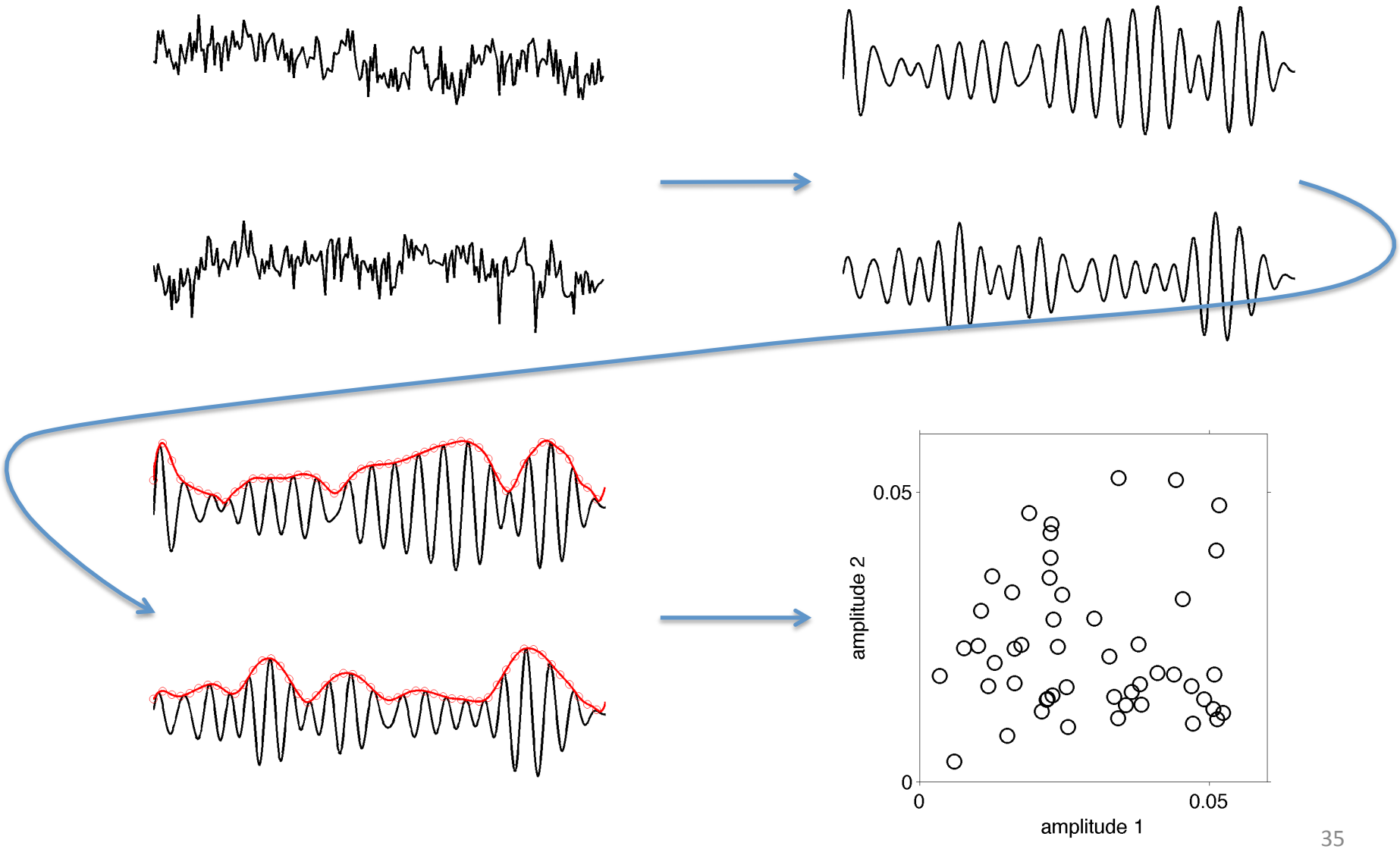
# Spectrally-resolved C-metrics

- amplitude/power (envelope) correlation
- phase difference consistency measures
- spectrally-resolved Granger causality
- cross-frequency interactions

# Why use spectrally-resolved metrics

- Oscillatory activity is a prominent feature in ongoing and event-related MEG signals
- Phase synchronisation may be an operational mechanism facilitating neuronal communication
- Overlap between topology of RSNs in fMRI with oscillatory networks observed with MEG

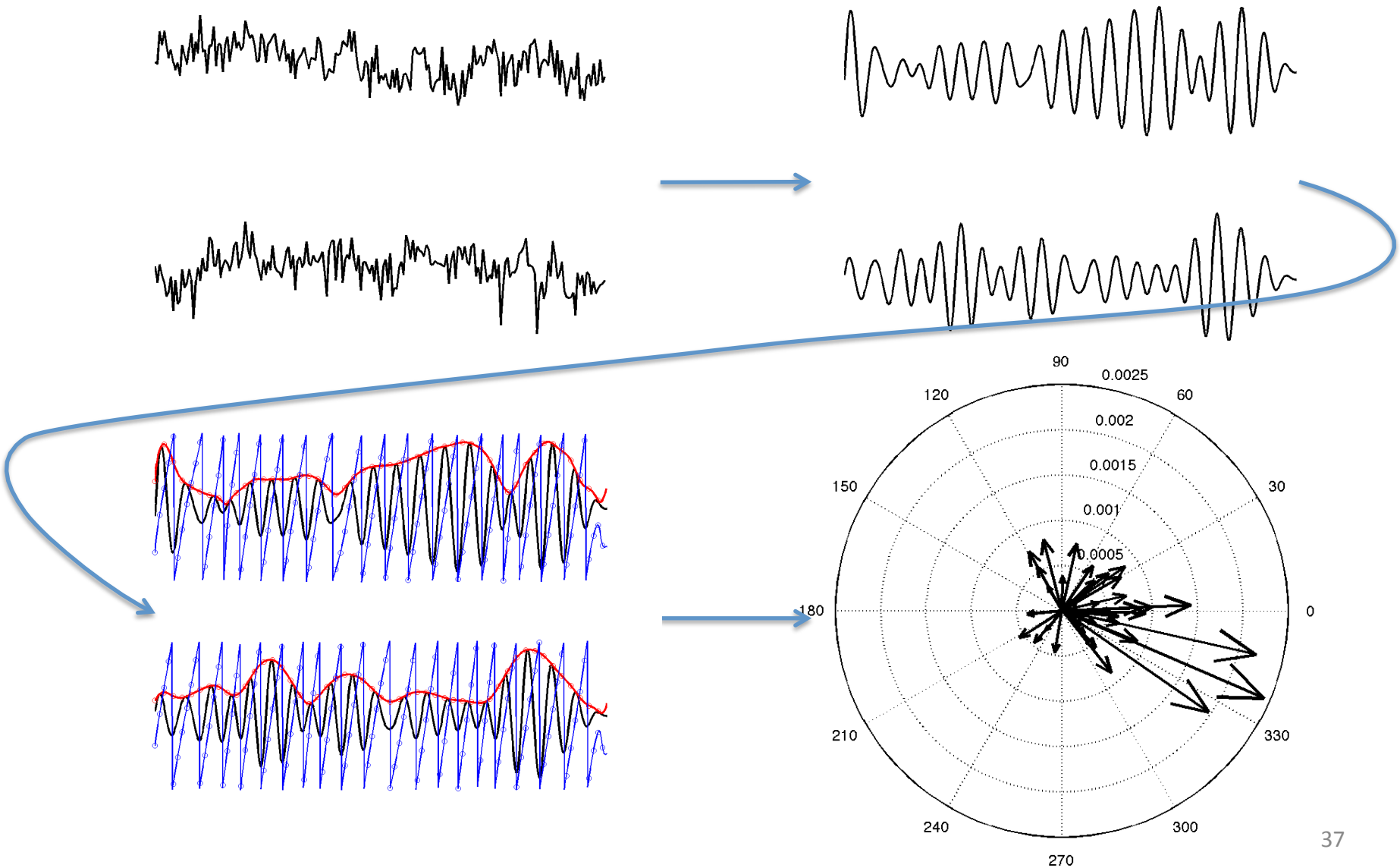
# Amplitude/power (envelope) correlation



# Amplitude/power (envelope) correlation

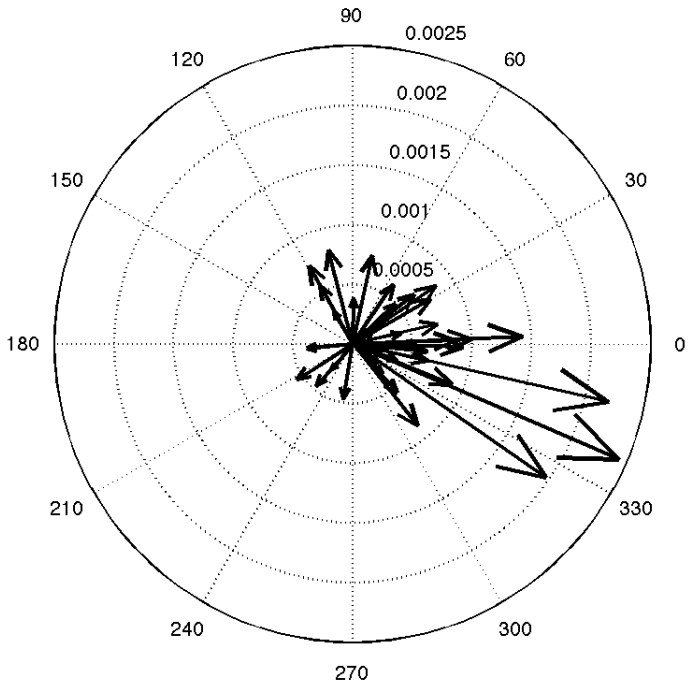
- In HCP a.k.a. BLP (band-limited power) correlation
- Used as connectivity metric in the rMEG data
- Provide 'static' connectivity estimates (estimating correlation in windows, average across the whole scan duration)
- Provide 'dynamic' connectivity estimates (based on a sliding window)

# Phase difference consistency measures



# Phase difference consistency measures

- Coherence
- Phase locking value
- Imaginary part of coherency
- Phase slope index
- Phase lag index
- Weighted phase lag index



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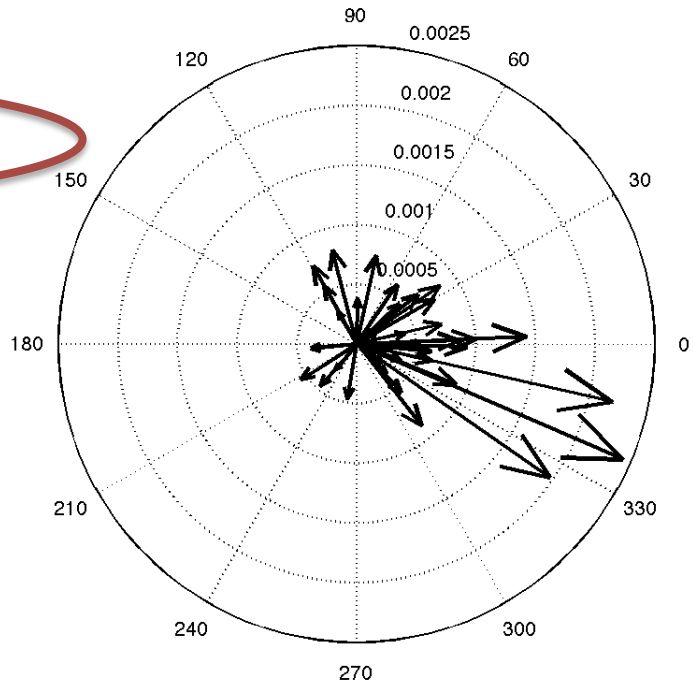
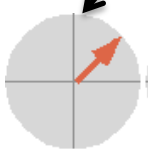


# Coherence

$$x_1 x_2^* = A_1 e^{i\varphi_1} \times A_2 e^{-i\varphi_2} = A_1 A_2 e^{i(\varphi_1 - \varphi_2)}$$

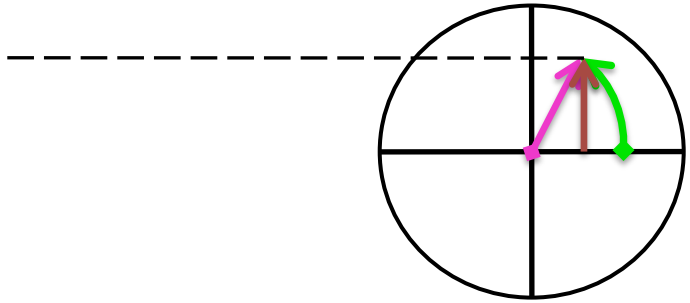
single trial cross-spectral density



# Imaginary part of coherency

$$\text{Coherency} = \frac{1/N\,\Sigma A_1 A_2 e^{i(\varphi_1-\varphi_2)}}{\sqrt{(1/N\,\Sigma A_1^2)(1/N\,\Sigma A_2^2)}} = Ce^{i\Delta\varphi}$$

Imaginary part of coherency



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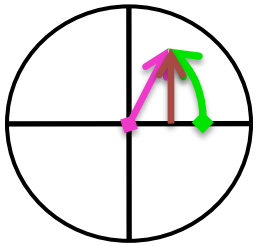

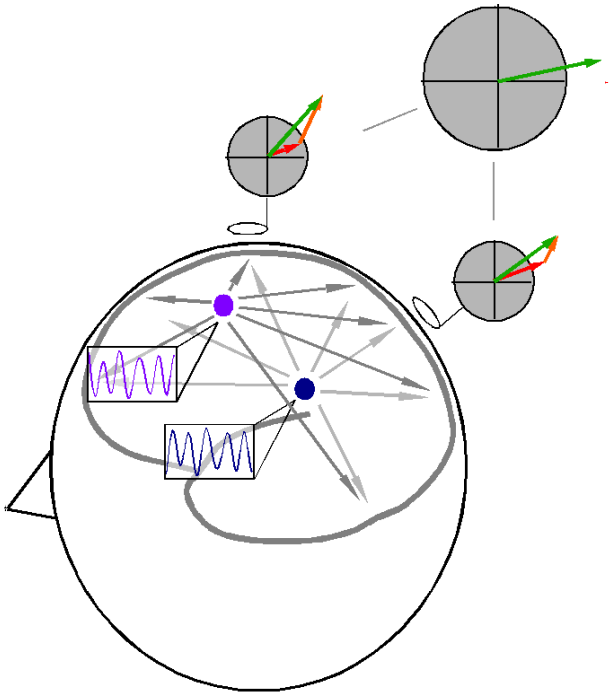

Im(coherency) ≠ 0

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# Parcellations and MEG

- Motivation: dimensionality reduction
  - Number of independent sources estimable per timeslice is limited anyway: <250
  - ‘smoothing’ of spatial noise
  - Allows for manageable-sized time-resolved connectivity matrices
- Challenge: optimal parcellation is unknown
  - Likely depends on data
  - When (in the course of analysis pipeline) to parcellate?
- Next MEG release: parcellation of connectomes based on the Yeo 2011 paper (functional parcellation based on resting state connectivity)

Thanks for listening