Spatiotemporal network dynamics from human brainwave data

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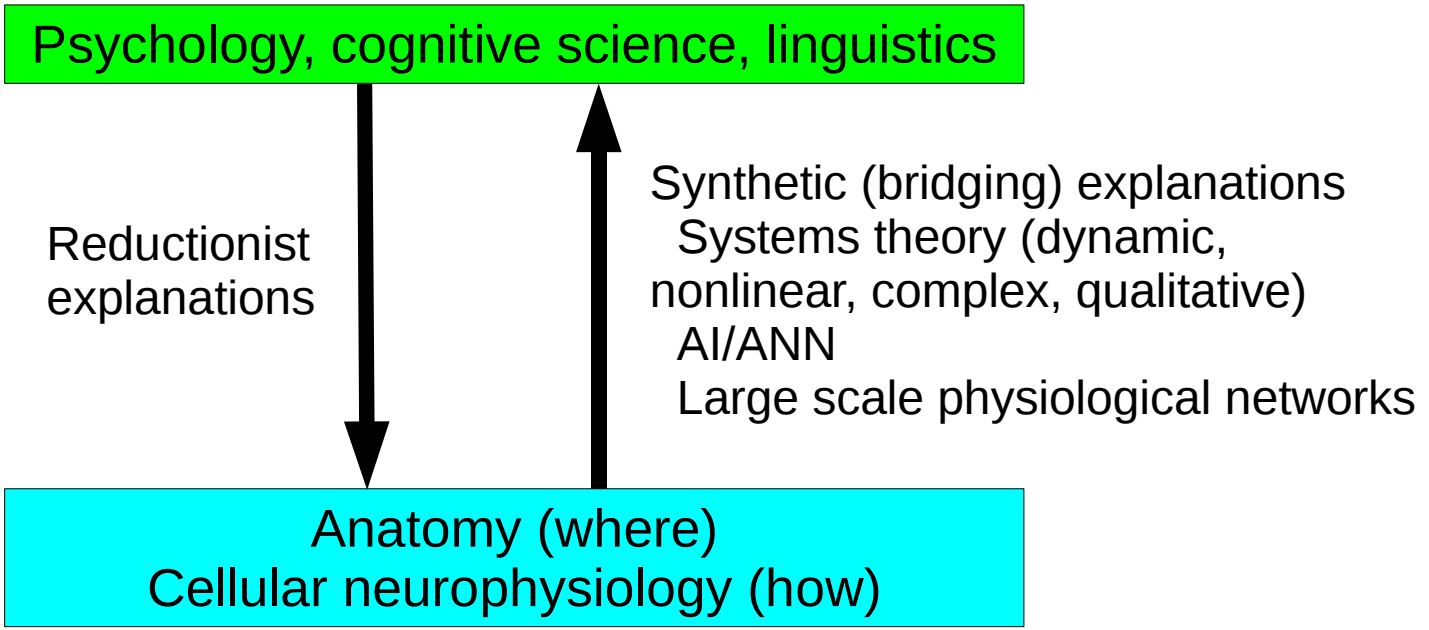
- Background and motivation
- Network identification methods
  - Instantaneousness Phase Synchrony
    - Phase Locking Value (PLV)
    - Normed Aggregate synchrony matrix
  - Composite synchrony profile (CSP)
    - Deterministic clustering algorithm
- Results
  - Seizure
  - Word recognition
- Summary and future directions

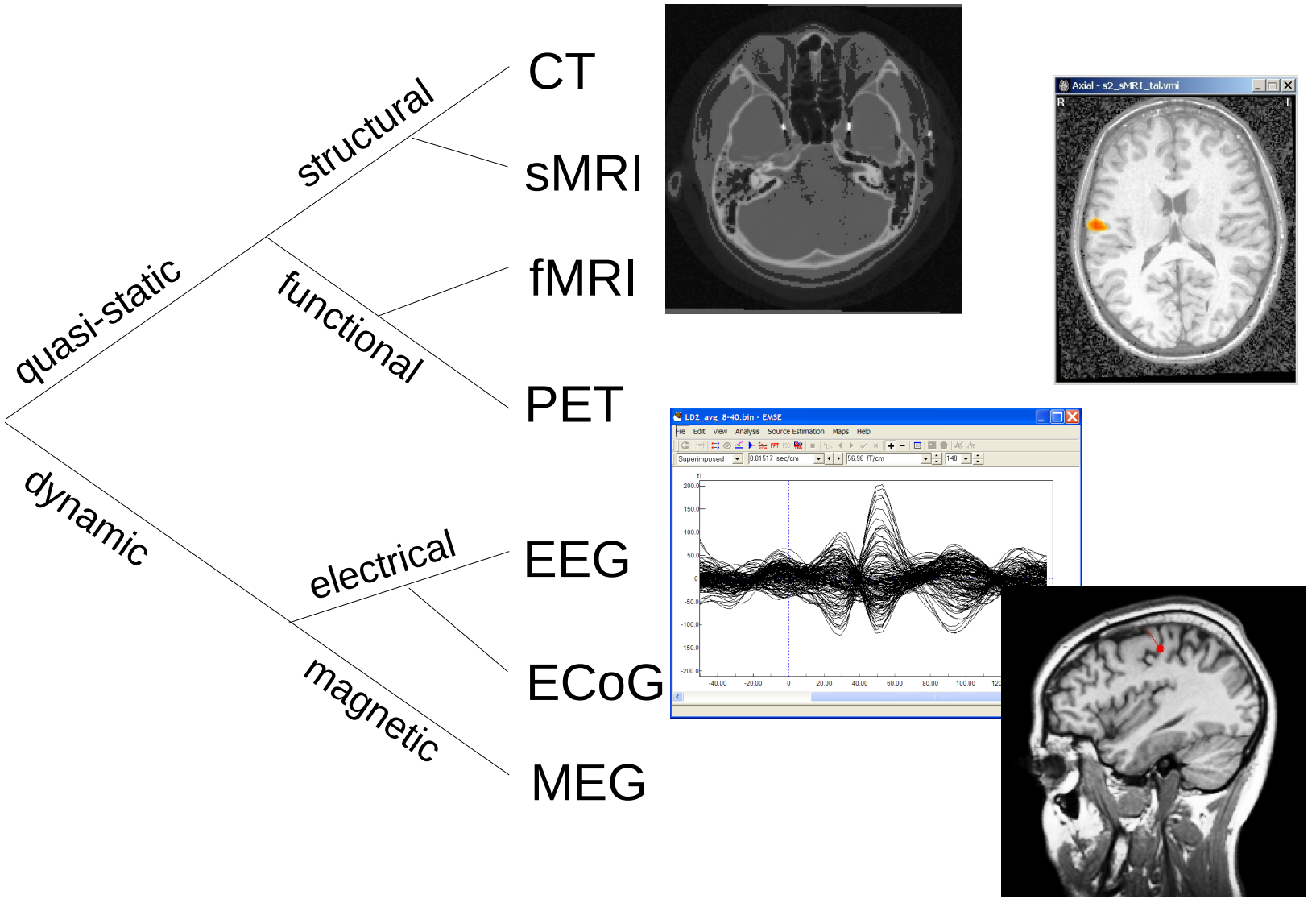
Background and Motivation

Explanatory levels in neuroscience:

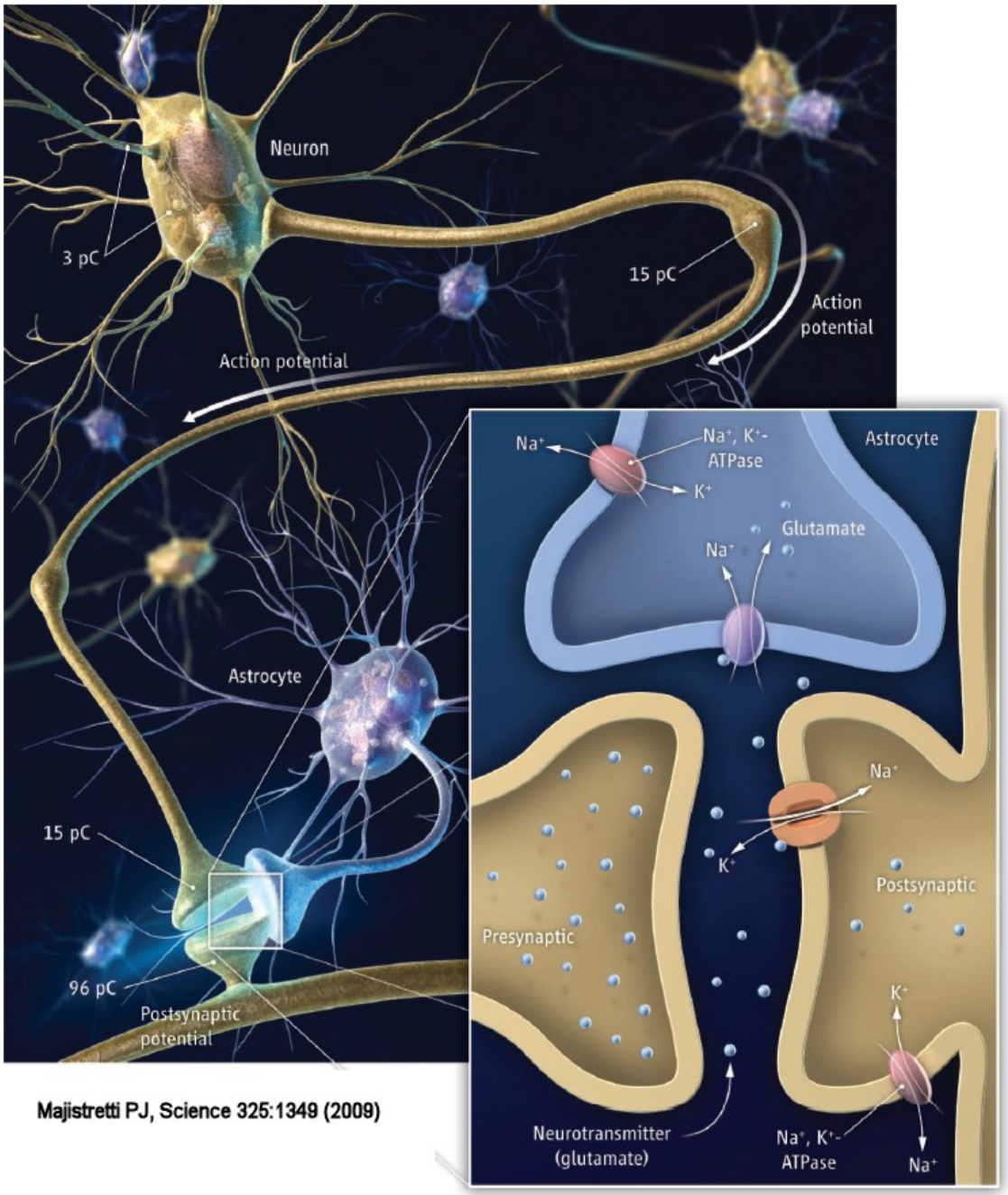
Ways of talking about brains and behavior



Where does the human data come from? Brain Imaging Modalities

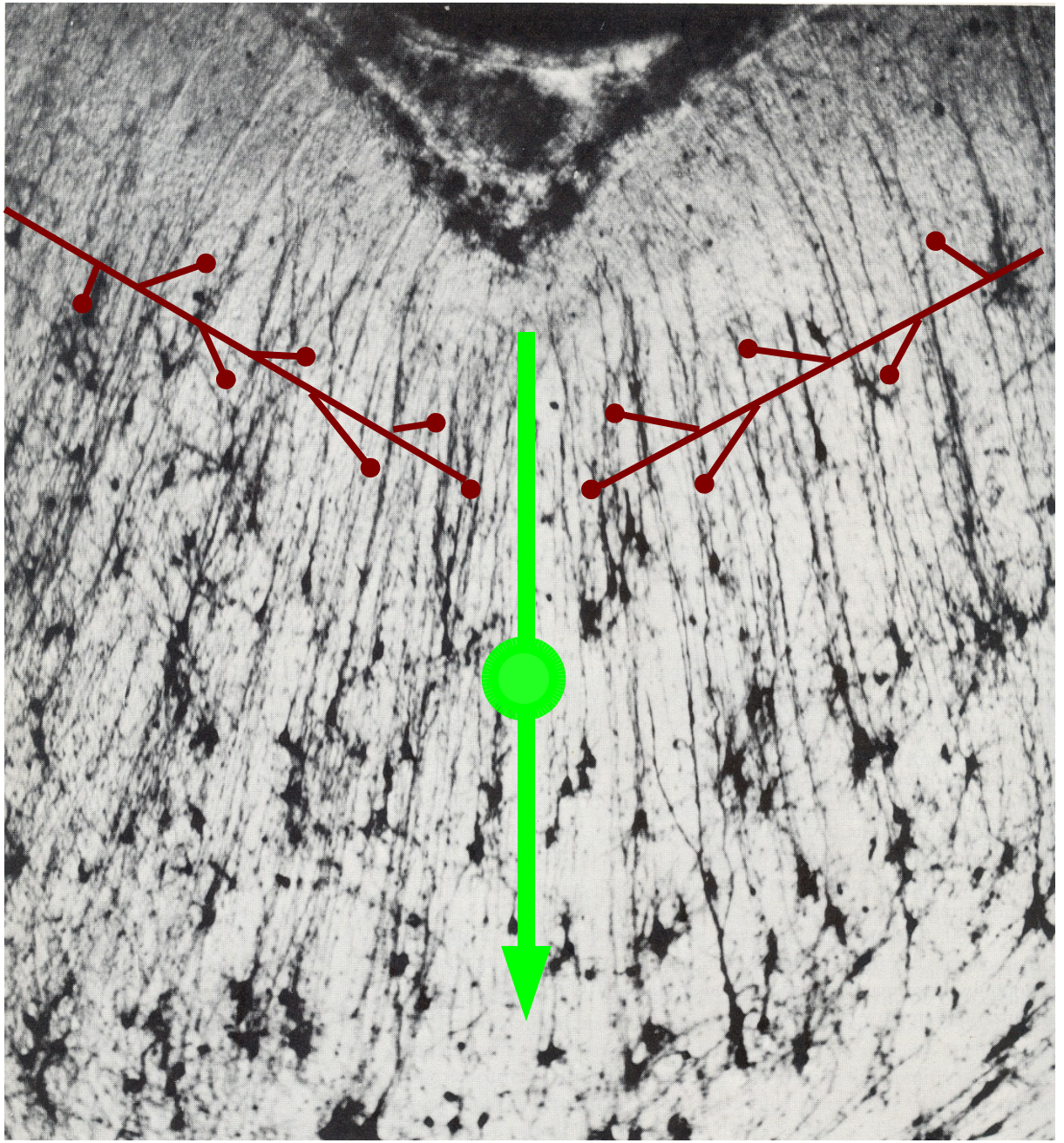


Brain Imaging - Cellular Physiology

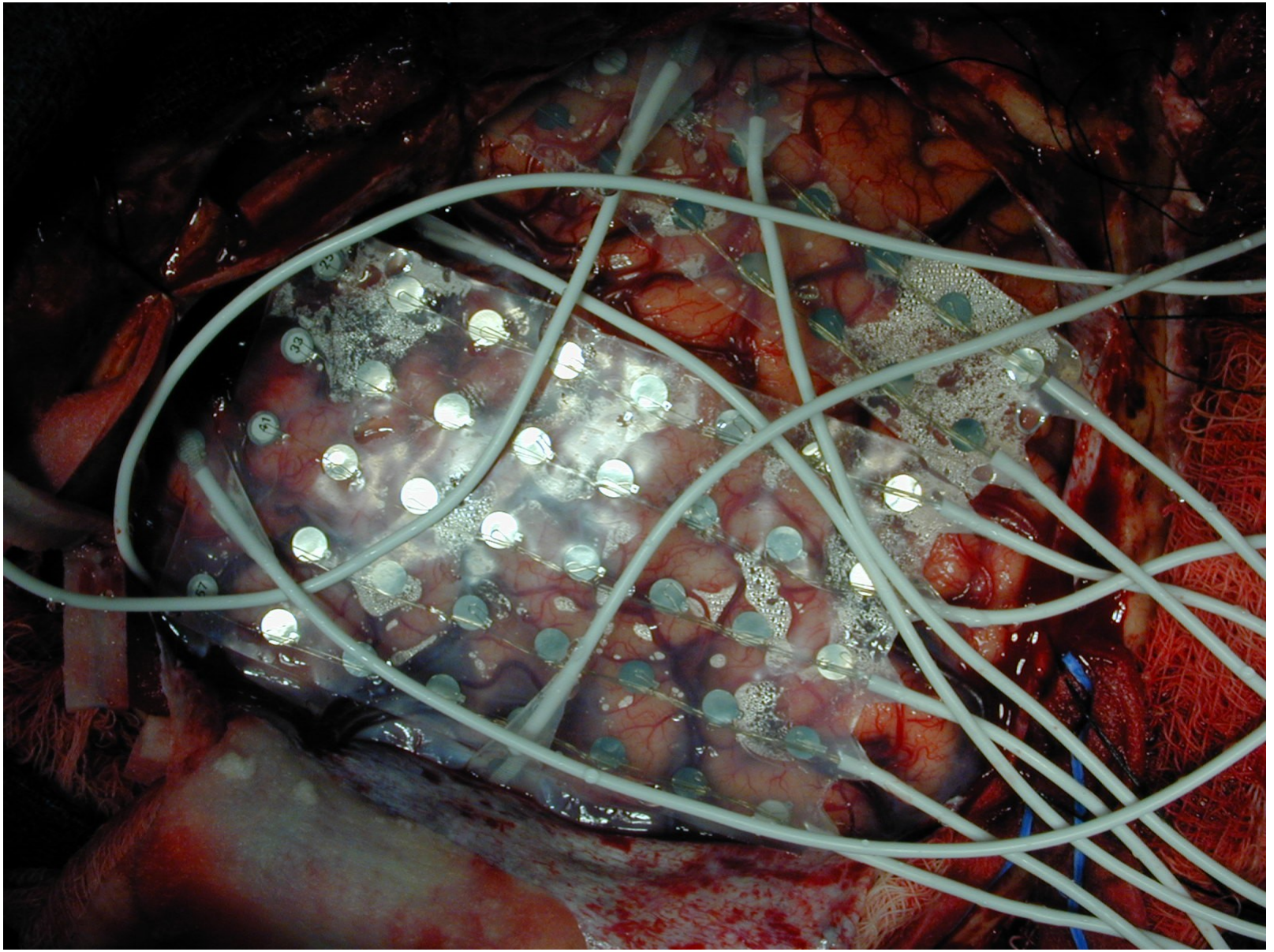


Majistretti PJ, Science 325:1349 (2009)

From neuron to field potentials

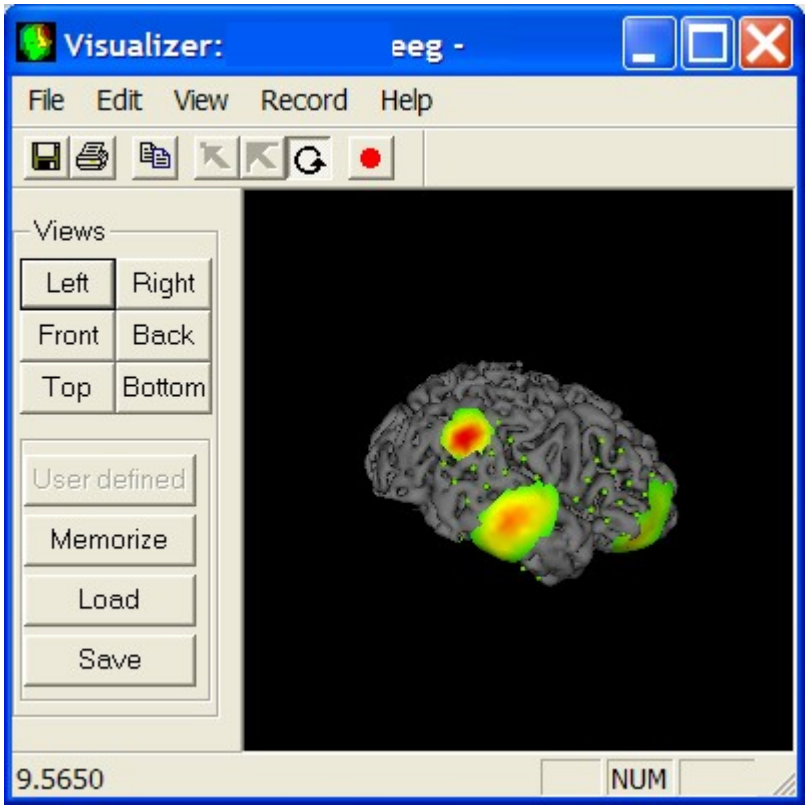


Electrocorticography - ECoG



R. Emerson MD, Columbia P&S

Clinical Seizure – Video ECoG



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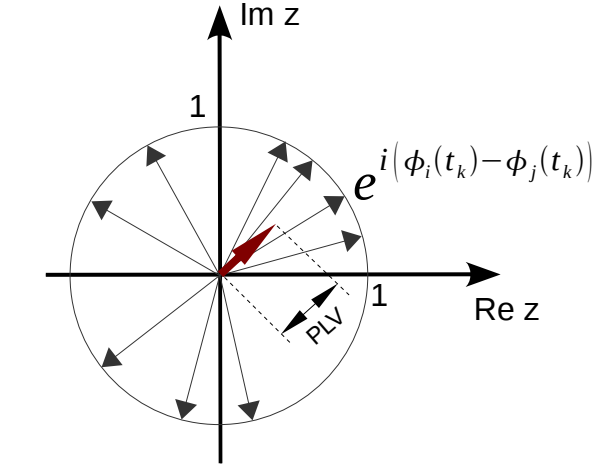
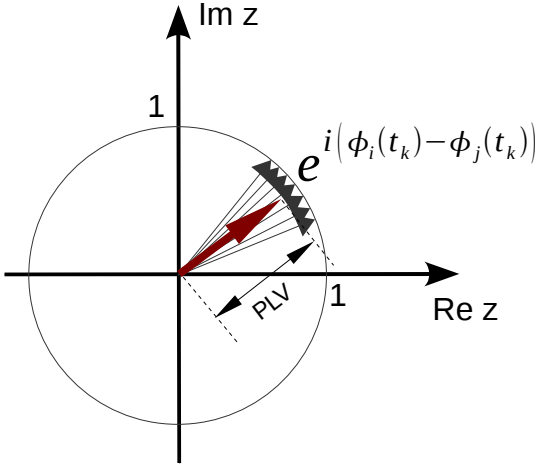
Phase Synchrony



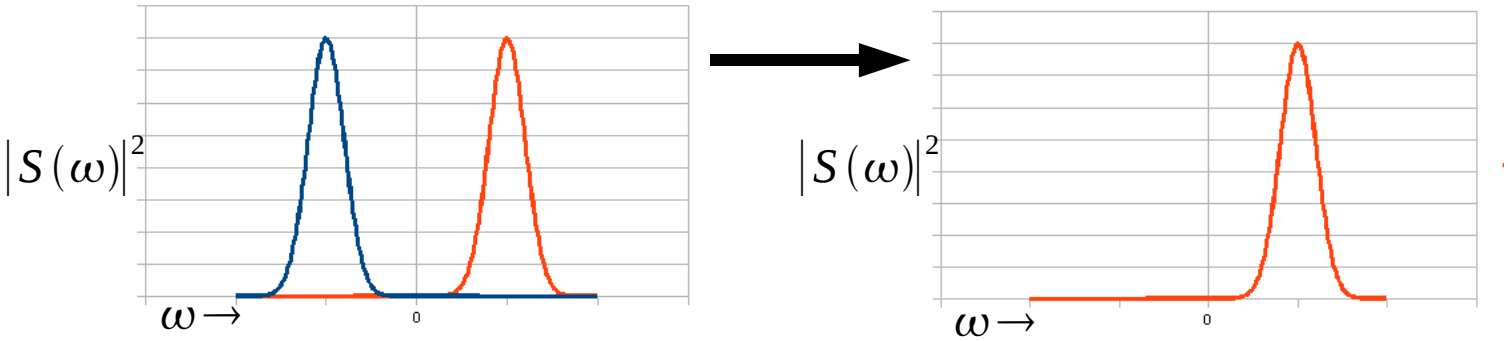
Poor phase synchronization



Good phase synchronization

Note: Phase synchrony is independent of signal amplitude

Hilbert Transform



$$z(t) = \frac{2}{\sqrt{2\pi}} \int_0^\infty S(\omega) e^{i\omega t} d\omega$$

$$s(t): \mathbb{R} \rightarrow \mathbb{R}$$
$$z(t): \mathbb{R} \rightarrow \mathbb{C}$$
$$s(t) \Leftrightarrow S(\omega)$$

$$z(t) = s(t) + \frac{i}{\pi} \int \frac{s(t')}{t - t'} dt'$$

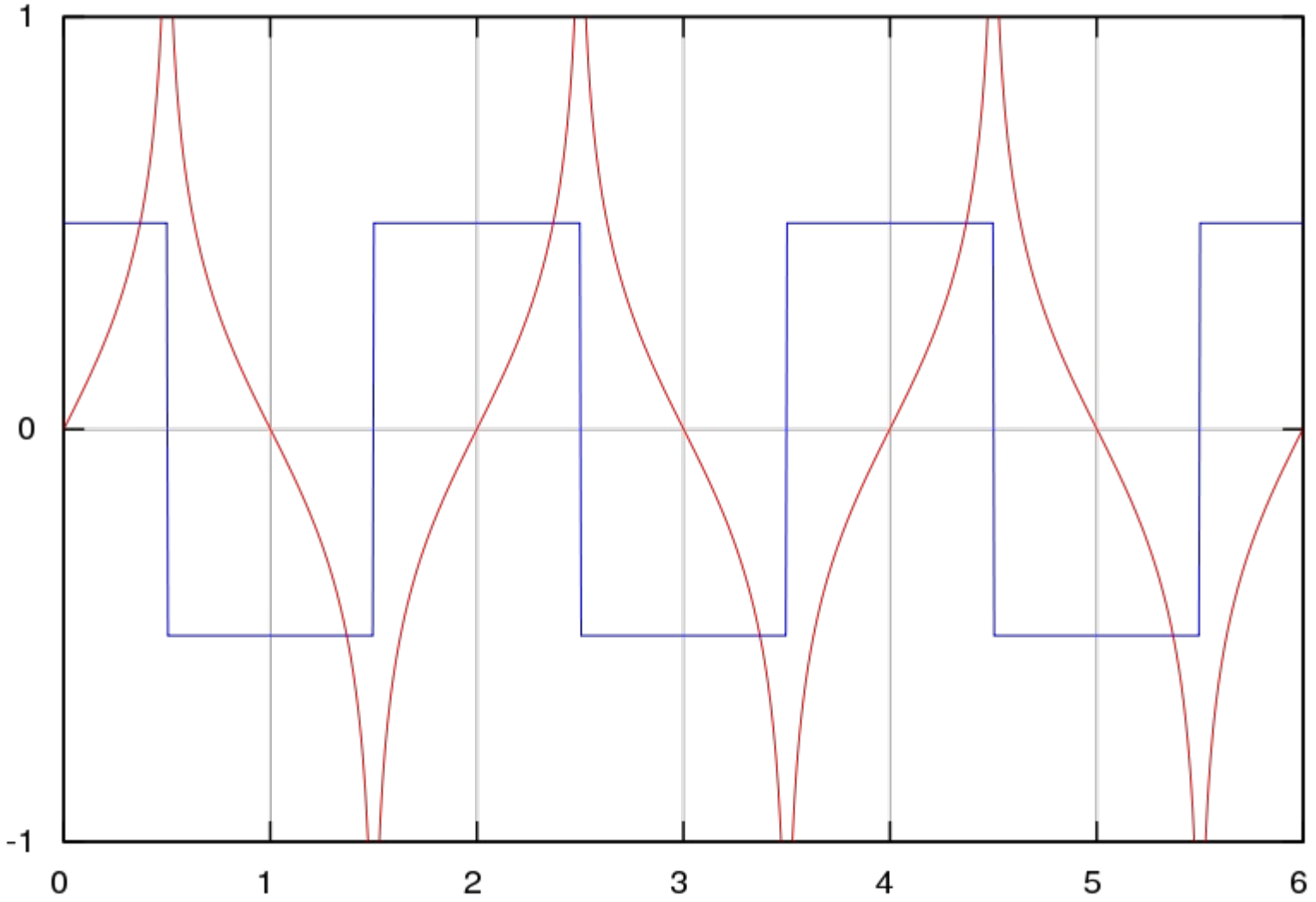
Hilbert transform

infinite support
singularity at t=t'
non-causal

$$z(t) = s(t) + i\hat{s}(t)$$

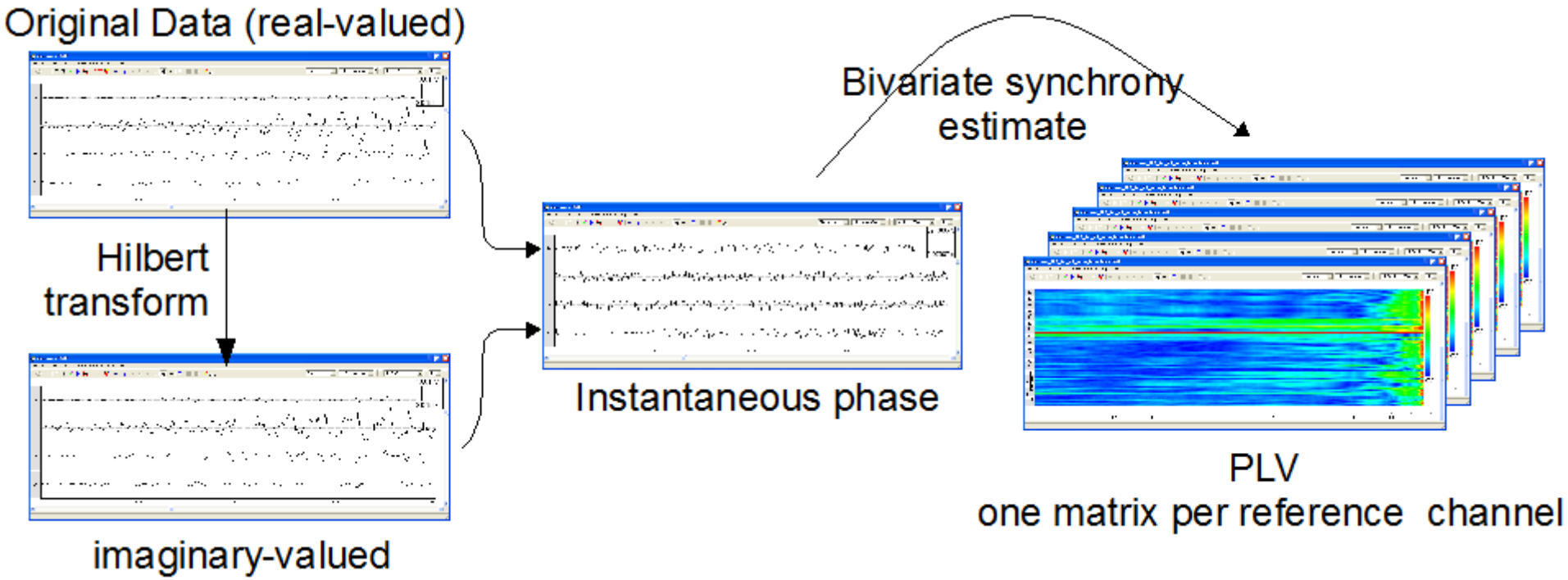
Cohen L, Time-Frequency Analysis, 1995

Hilbert transform – square wave

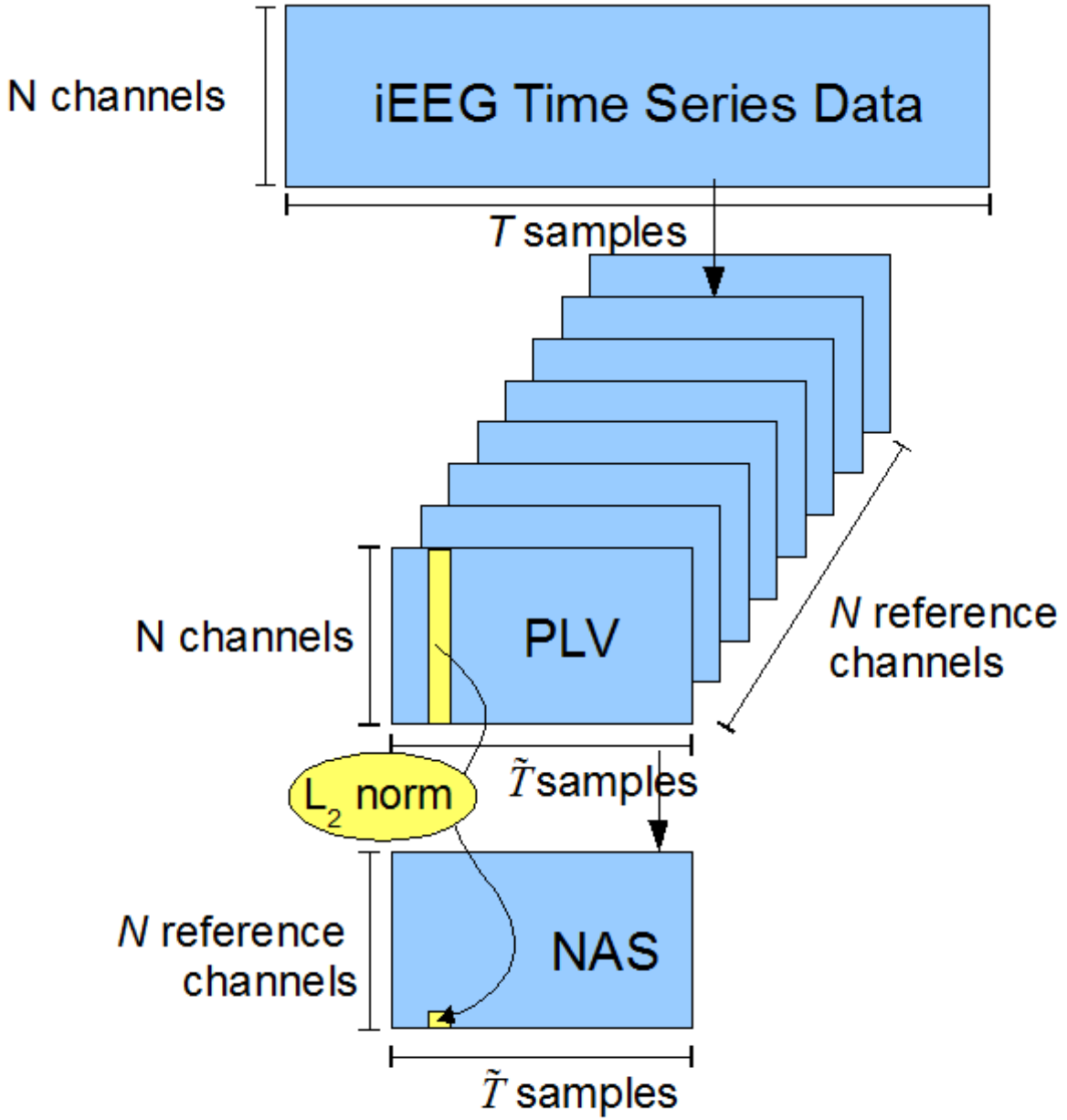


http://en.wikipedia.org/wiki/Hilbert_transform

Phase Locking Value - PLV

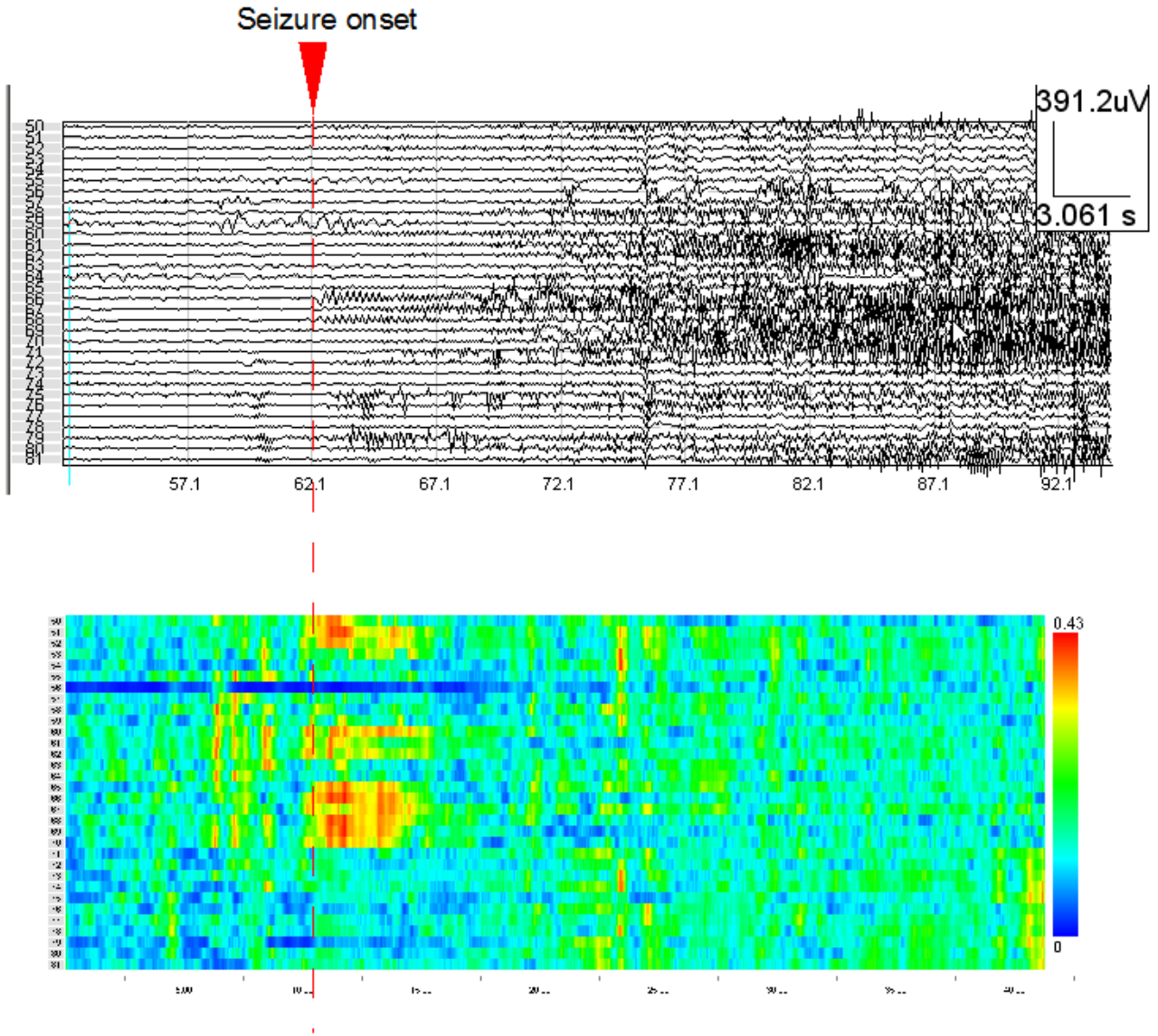


Normed Aggregate Synchrony Matrix - Algorithm

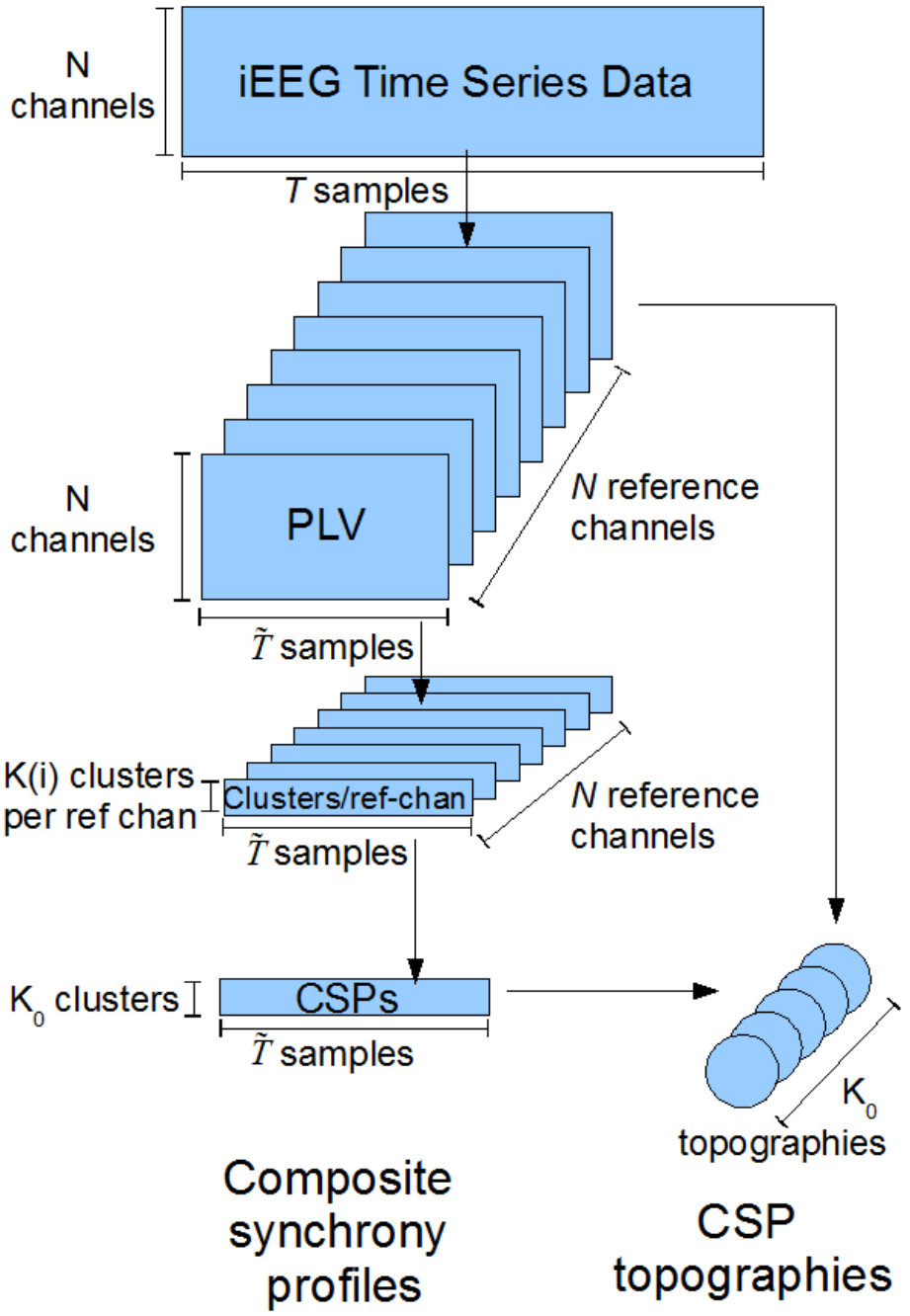


Normed aggregate synchrony matrix

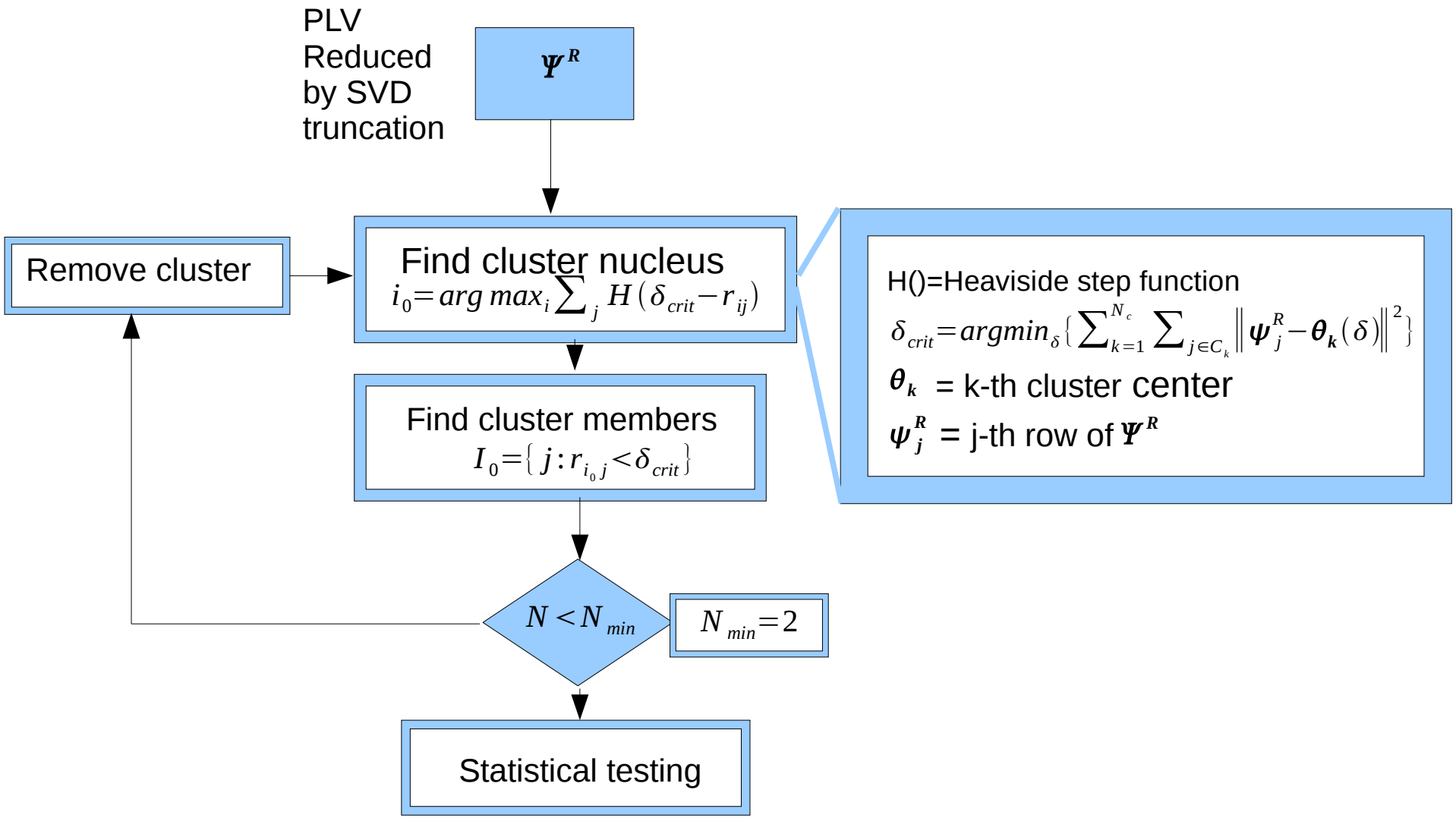
Normed Aggregate Synchrony Matrix – Seizure Data



Composite Synchrony (CSP) Algorithm



Deterministic clustering algorithm



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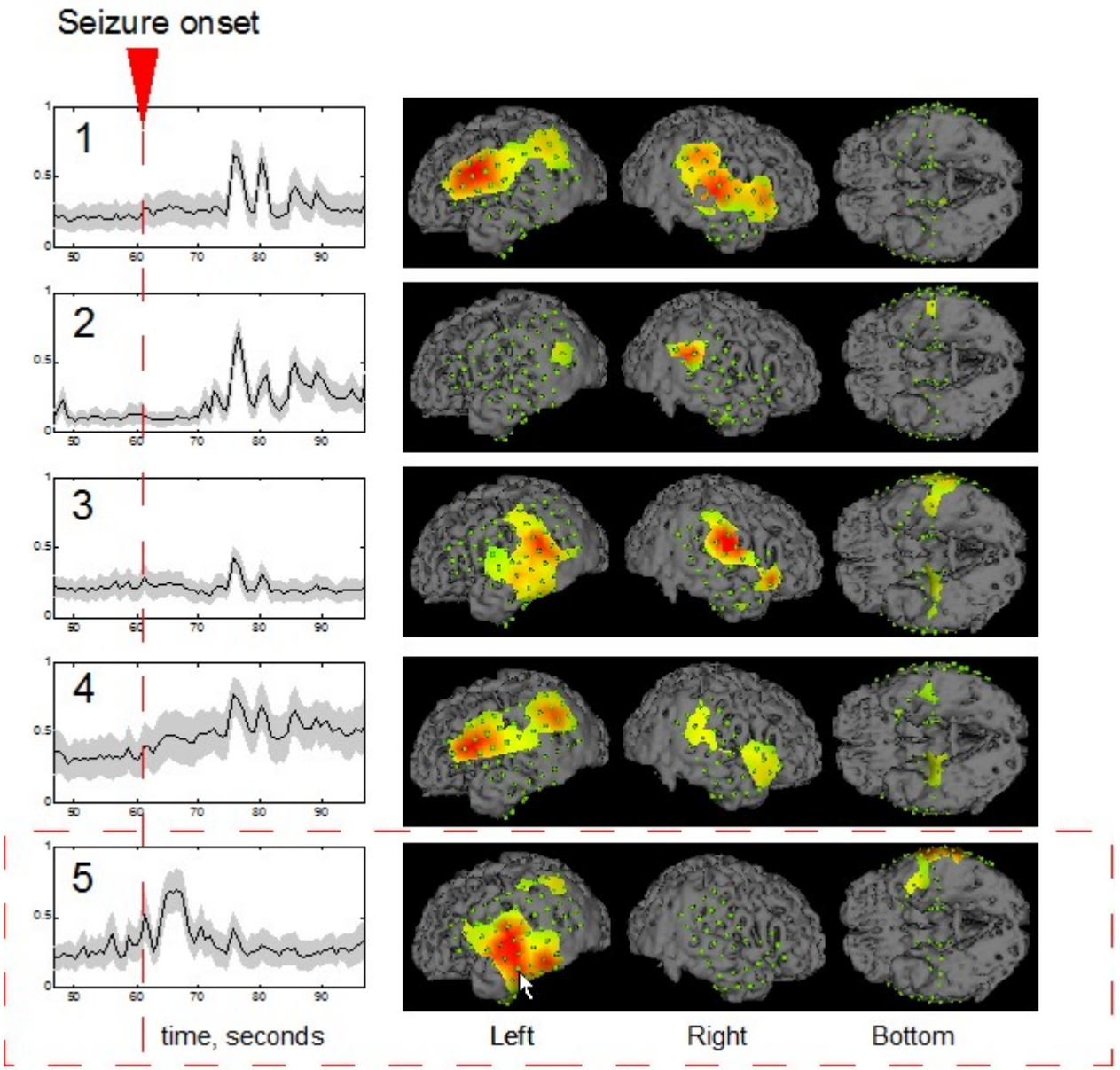
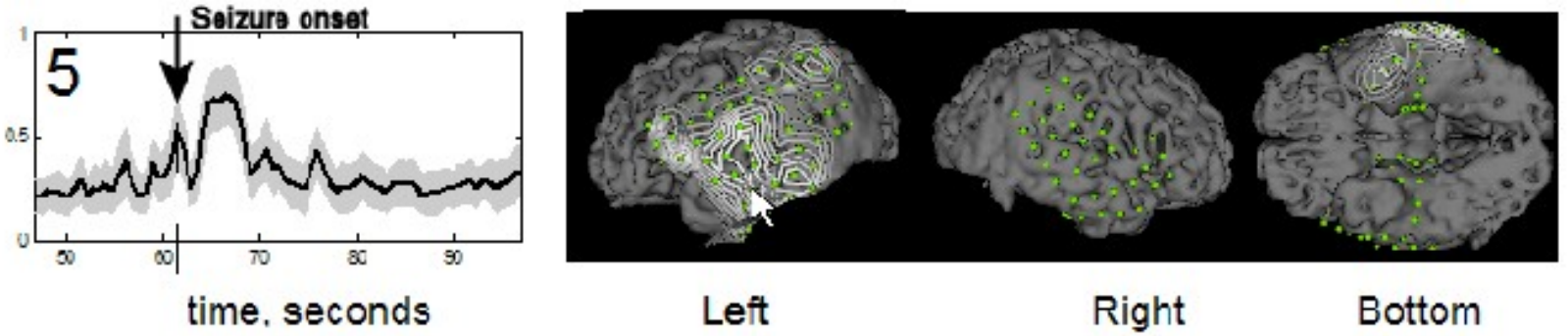
PLV/CSP – Seizure Data



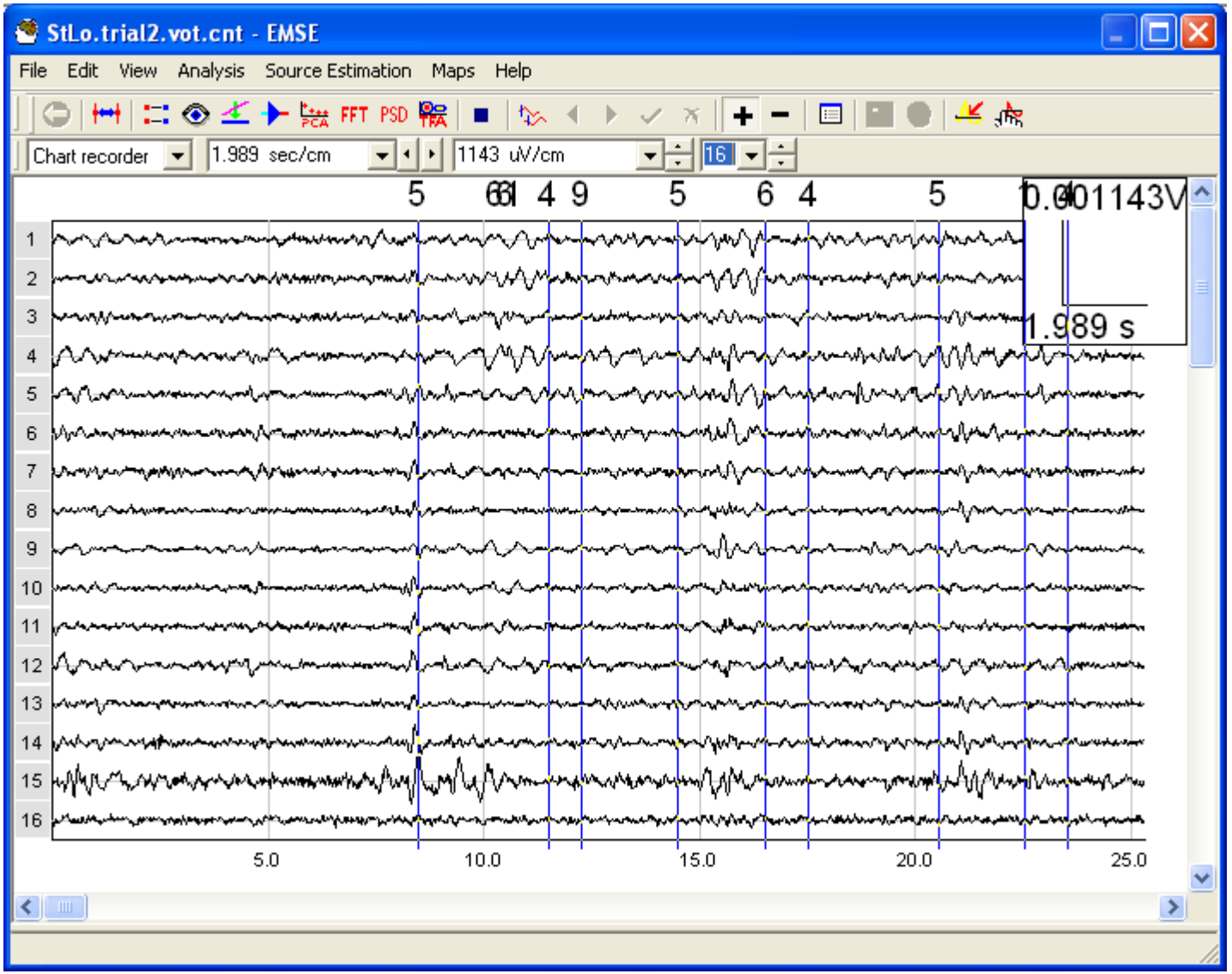
Ossadtchi et al., J Clin Neurophysiol (submitted)

PLV/CSP – Seizure Data

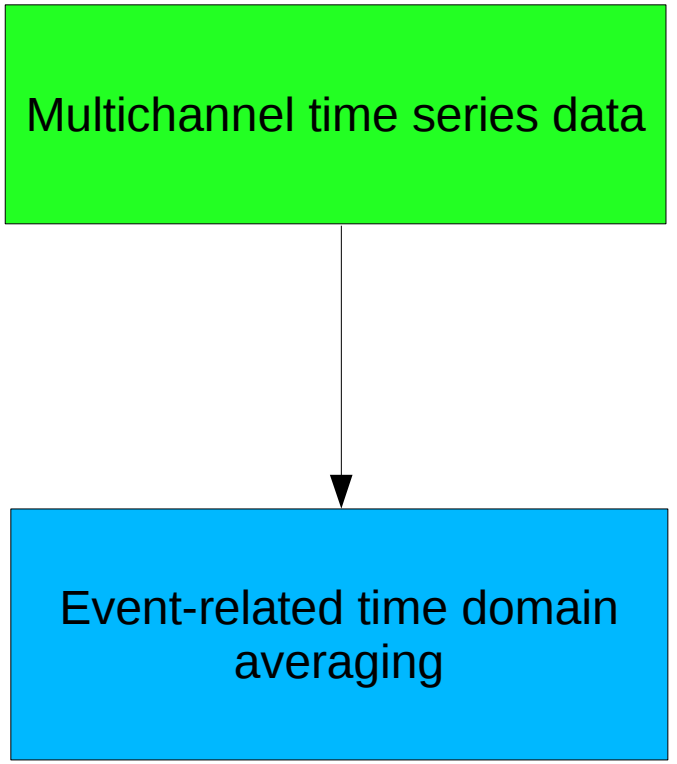


Ossadtchi et al., J Clin Neurophysiol (submitted)

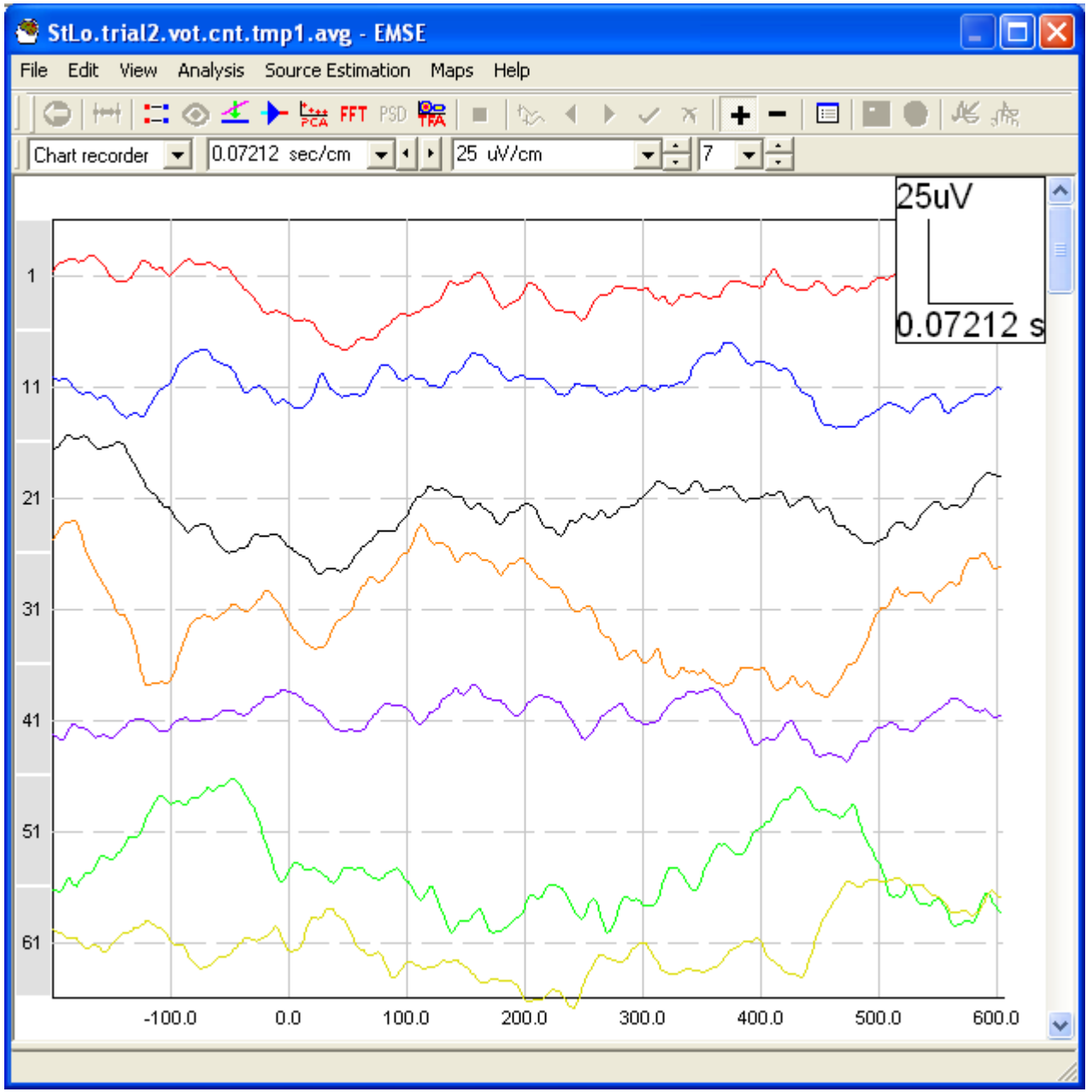
Event-related ECoG - Data



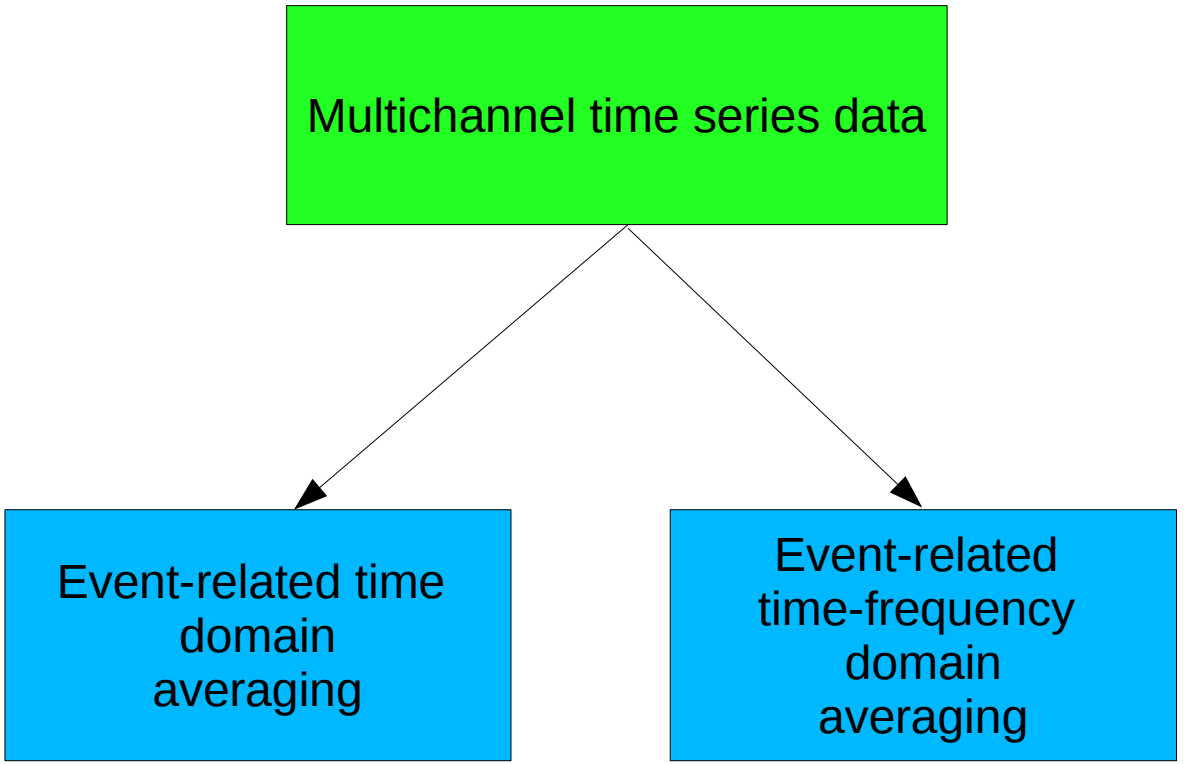
Event-related data analysis: Averaging



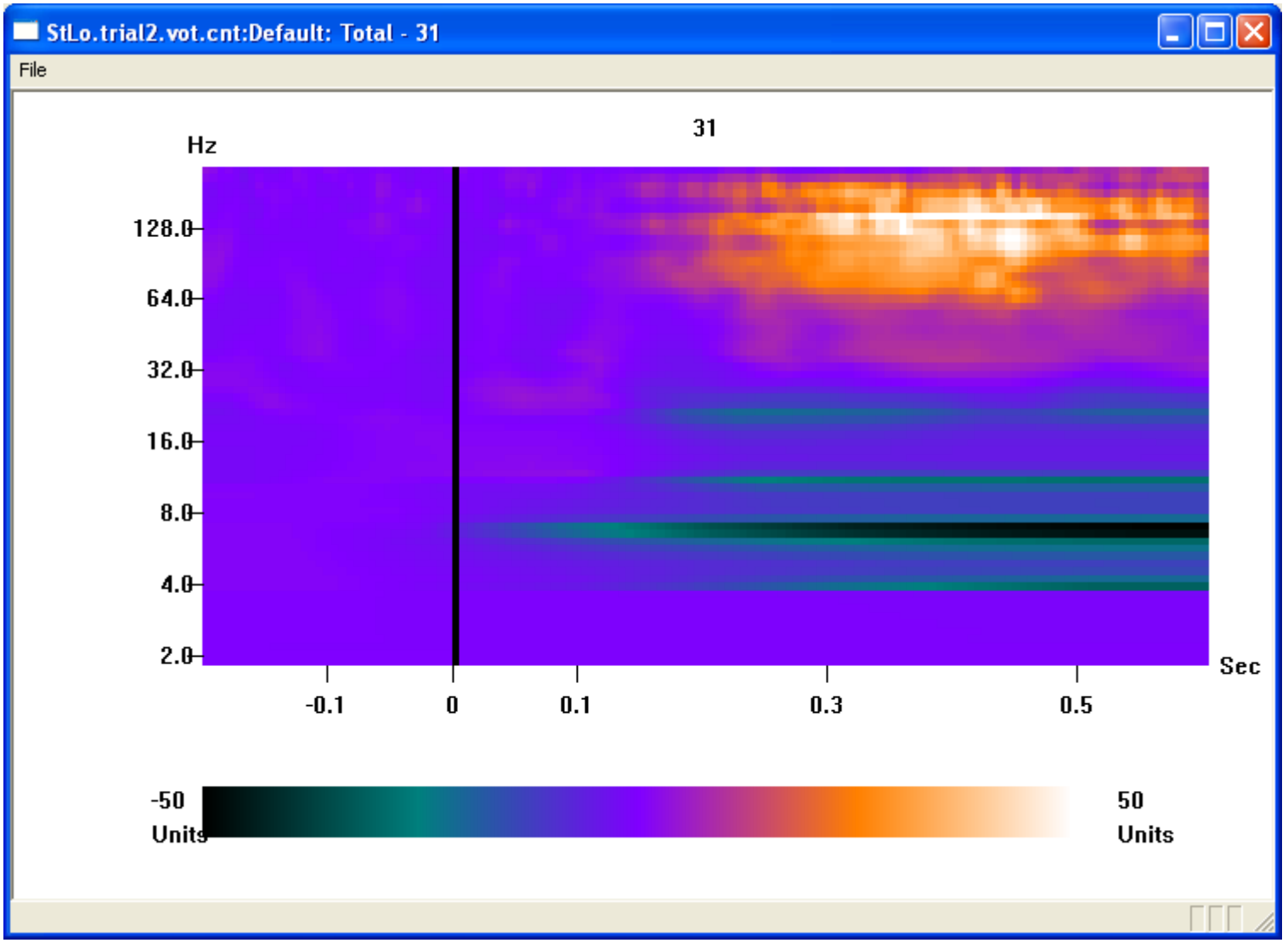
Event-related ECoG - Averaging



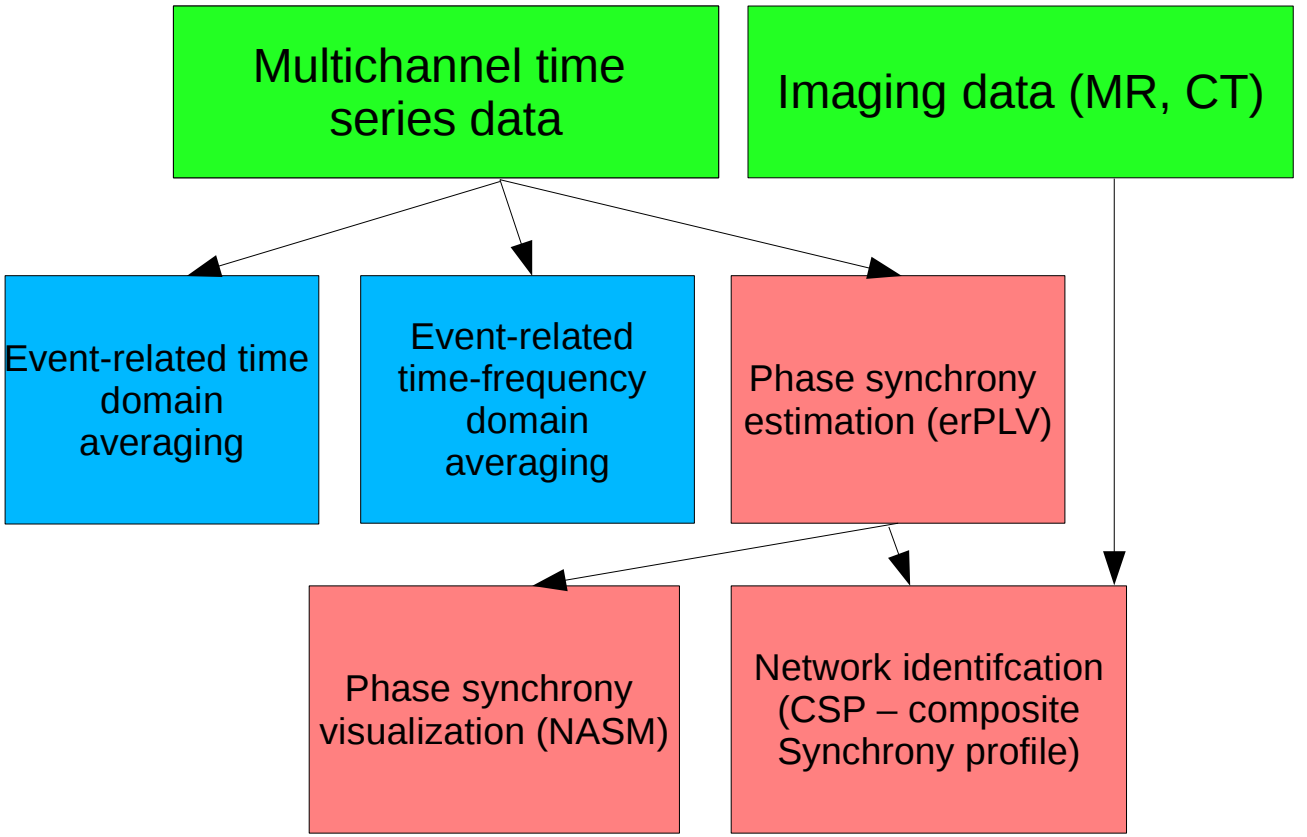
Event-related data analysis: Time-frequency Averaging



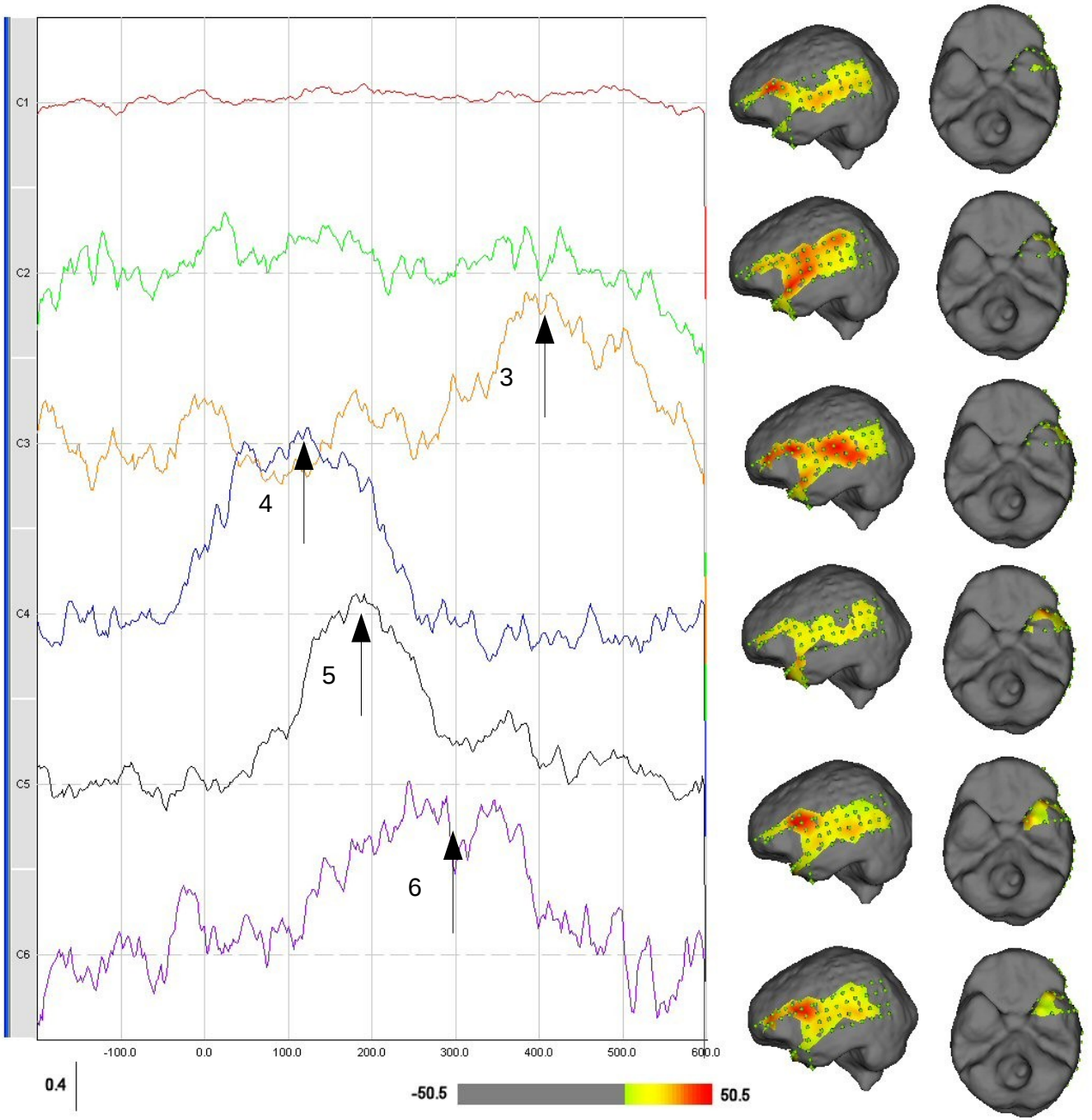
Event-related ECoG - Time-Frequency



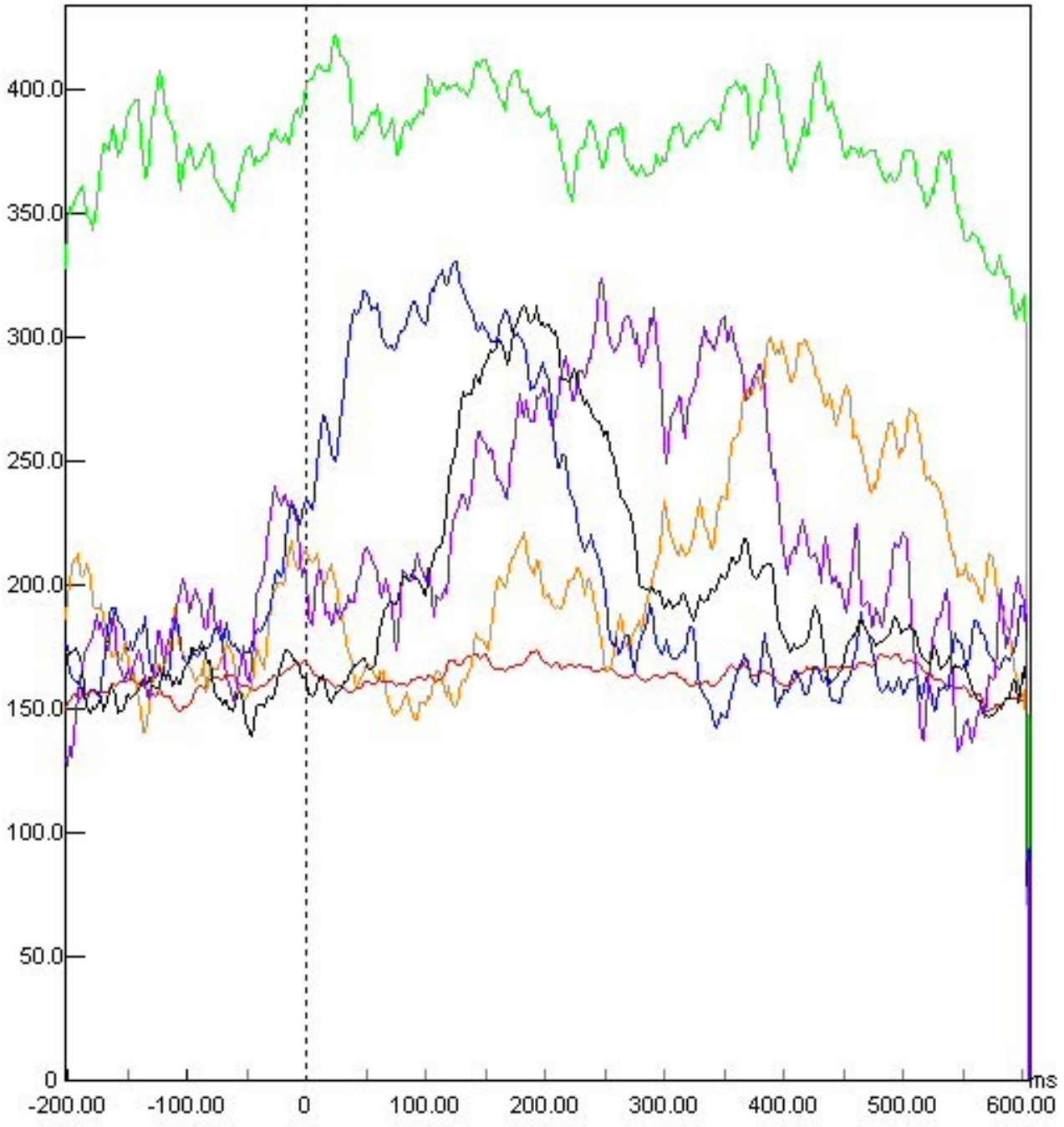
Event-related data analysis: network identification



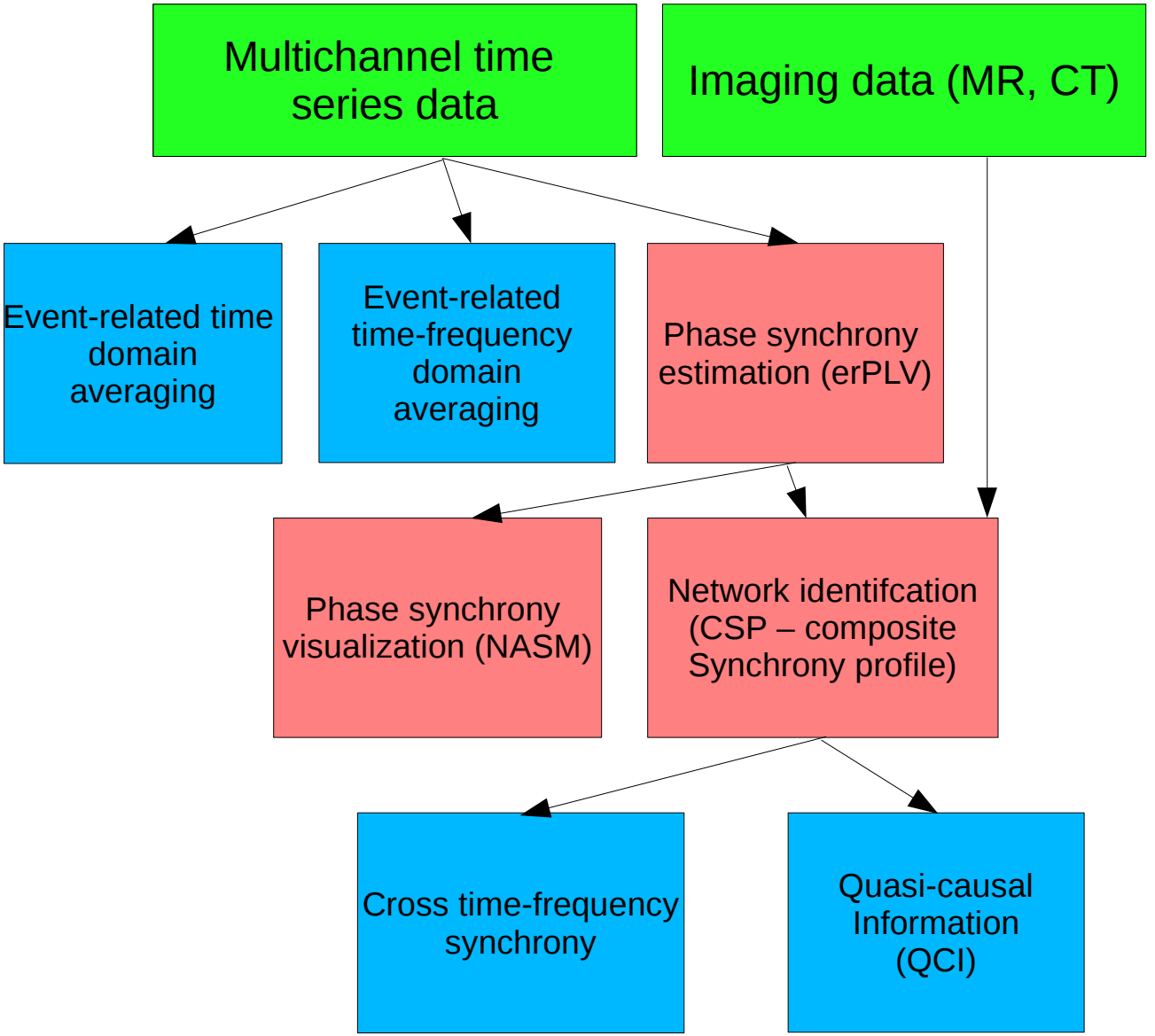
PLV/CSP – Event-related ECoG – word recognition task



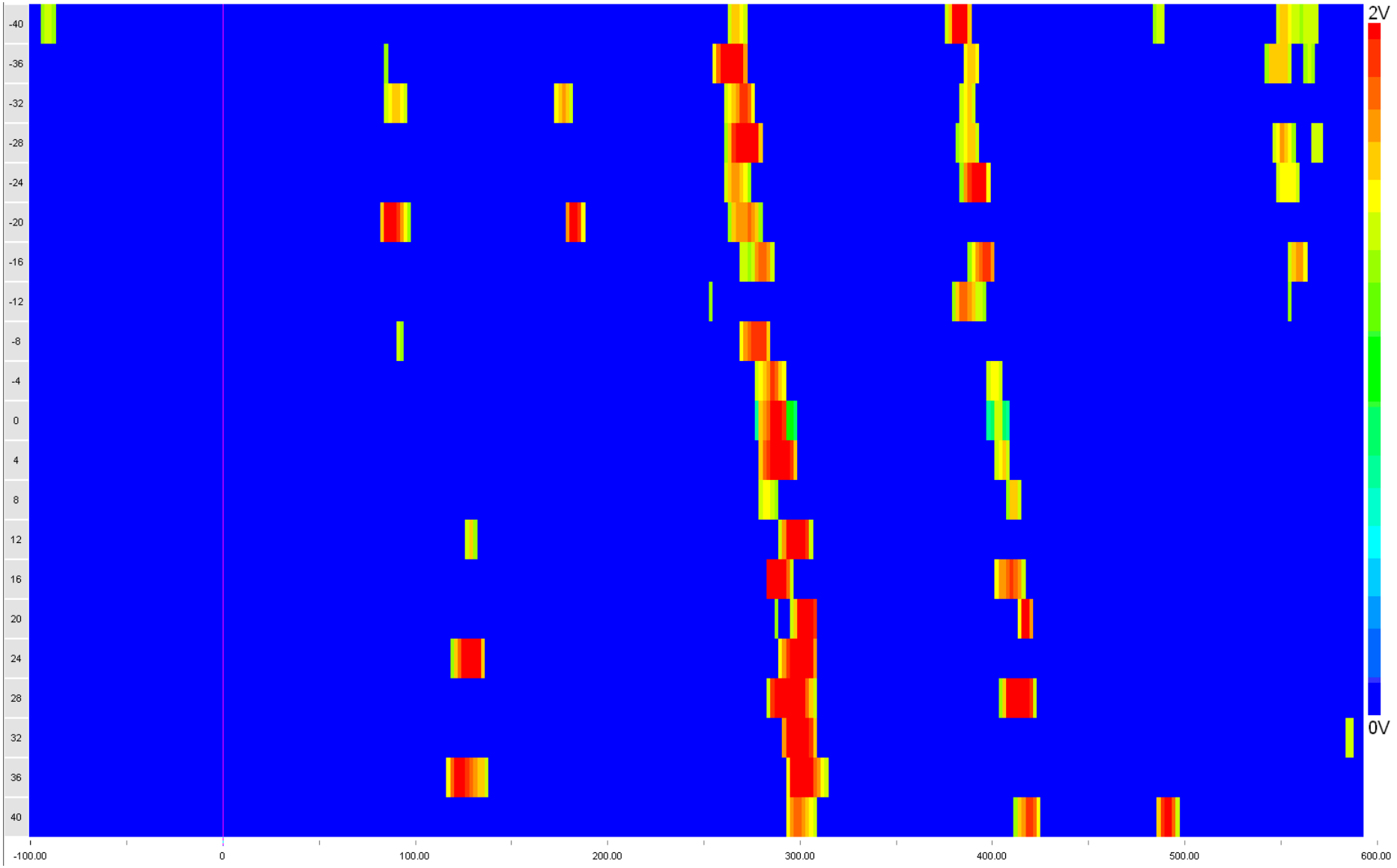
PLV/CSP – Event-related ECoG – word recognition task



Event-related data analysis: network characterization



QCI – Theta/High Gamma



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Conclusions

We describe procedures for identifying brain networks from electrophysiological data

- Normed aggregate synchrony
- Composite synchrony profile

When applied to seizure data, we find clinically reasonable seizure networks, including temporal/limbic and parietal/frontal

When applied to event-related data, we find evidence for a newly observed phenomenon, the network cascade

Future directions

- Basic Research
  - Verify and characterize network cascade
- Clinical Research
  - Networks and seizure onset
- Software technology
  - Verification and validation
  - Extension
  - Usability

Collaborators/Acknowledgements

St. Petersburg State University

- Alexei Ossadtchi

University of Chicago

- Leo Towle
- Michael Kohrmann

University of Tokyo

- Kyosuke Kamada

Source Signal Imaging

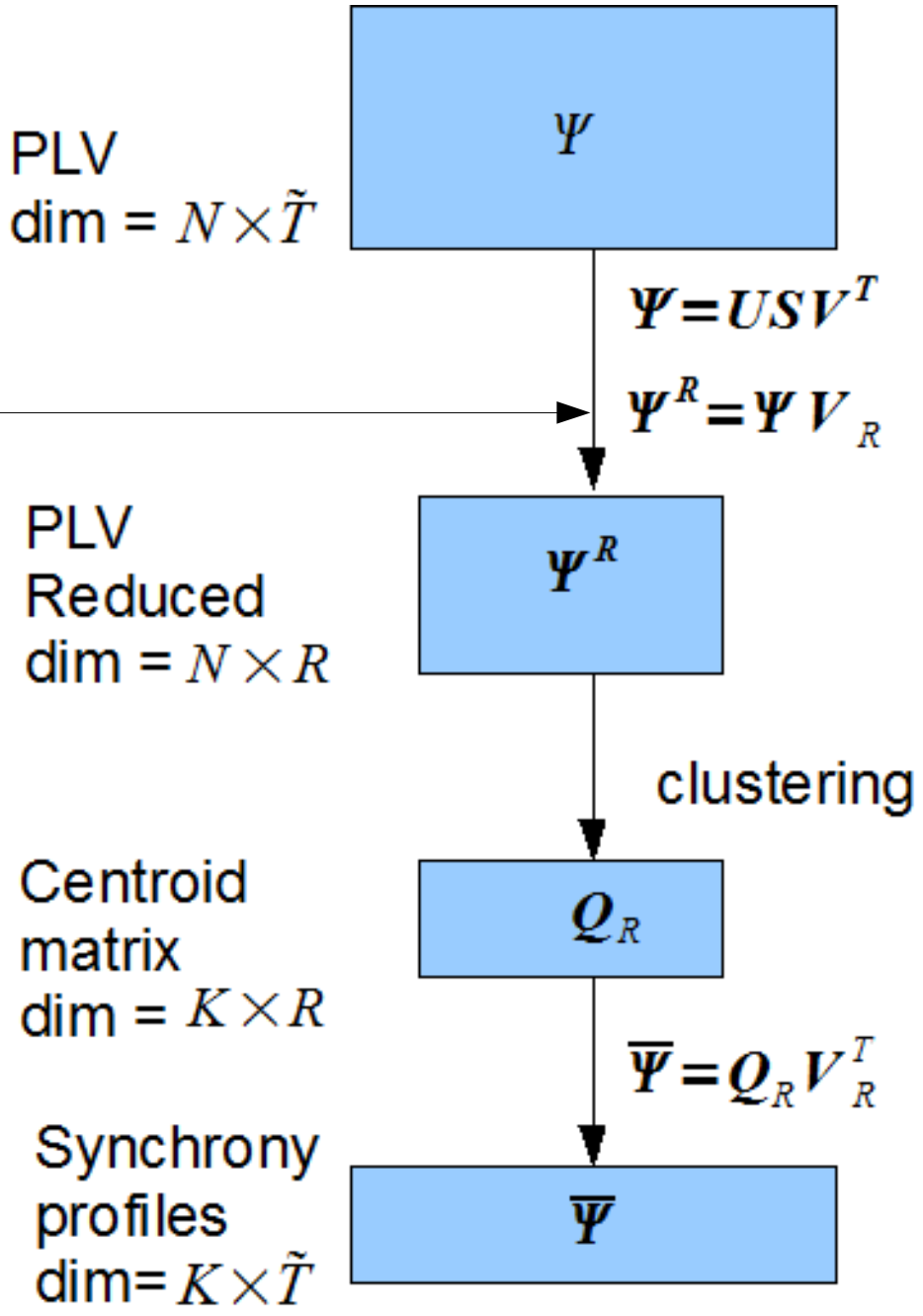
- Mark E. Pflieger
- Li Gao
- David Nichols
- Jandro Kirkish
- Don Lawson
- Demetrios Voreades
- Janet Henrickson

Support - NIH – NINDS, Source Signal Imaging

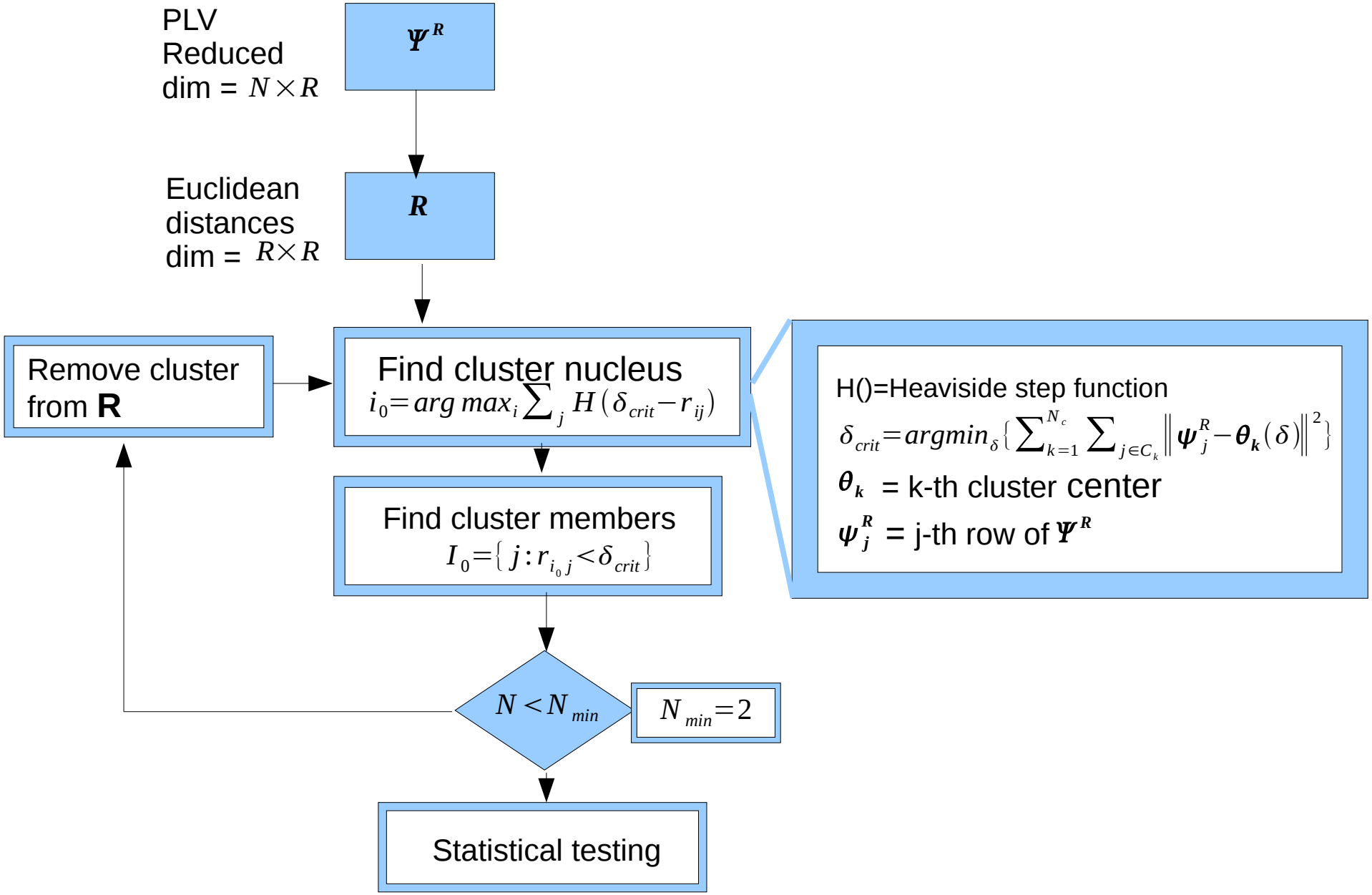
Thank you for your attention

Subspace clustering

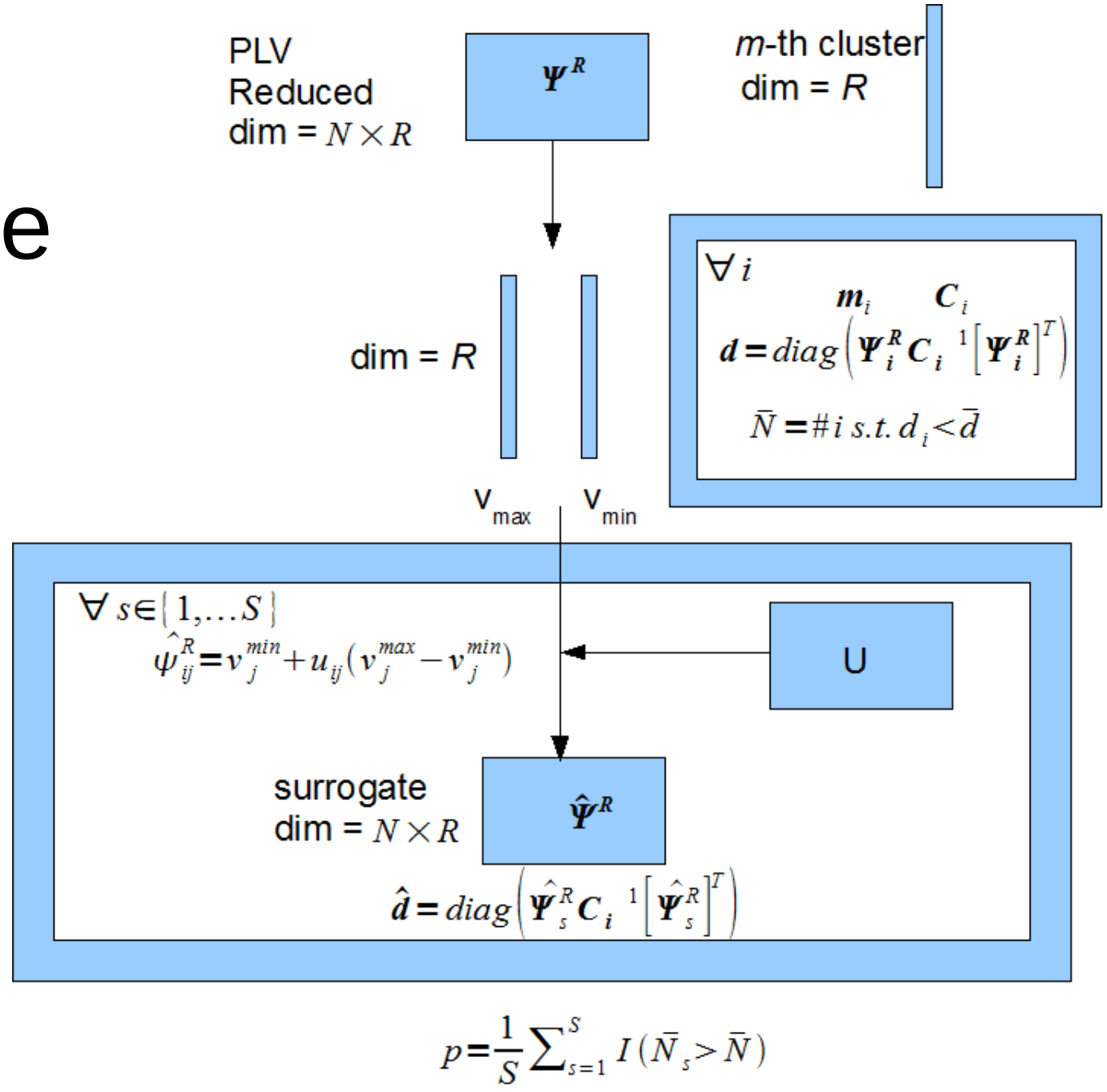
Subspace dimension R is determined by comparing the singular value spectrum $\boldsymbol{S}$ with the spectrum of a random matrix with the same Frobenius norm as $\boldsymbol{\Psi}$



Deterministic clustering algorithm



Cluster significance testing



$$p = \frac{1}{S} \sum_{s=1}^{S} I(\bar{N}_s > \bar{N})$$