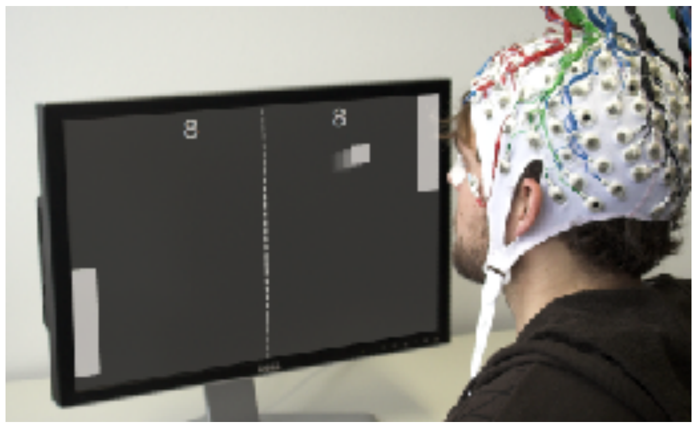
Algorithms for Brain Reading and Writing

Stefan Haufe

stefan.haufe@tu-berlin.de

Machine Learning, Technische Universität Berlin

“Reading” the brain

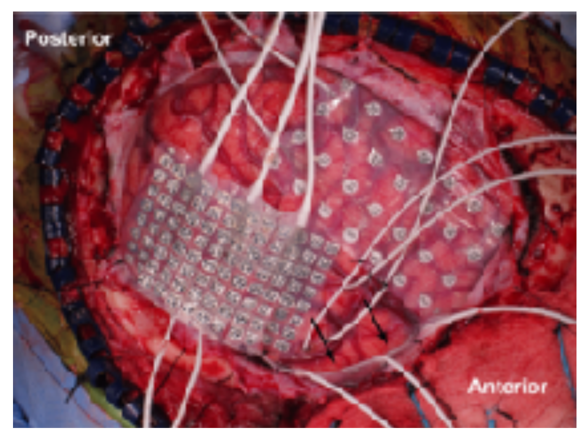


EEG

MRI

MEG

NIRS [3]



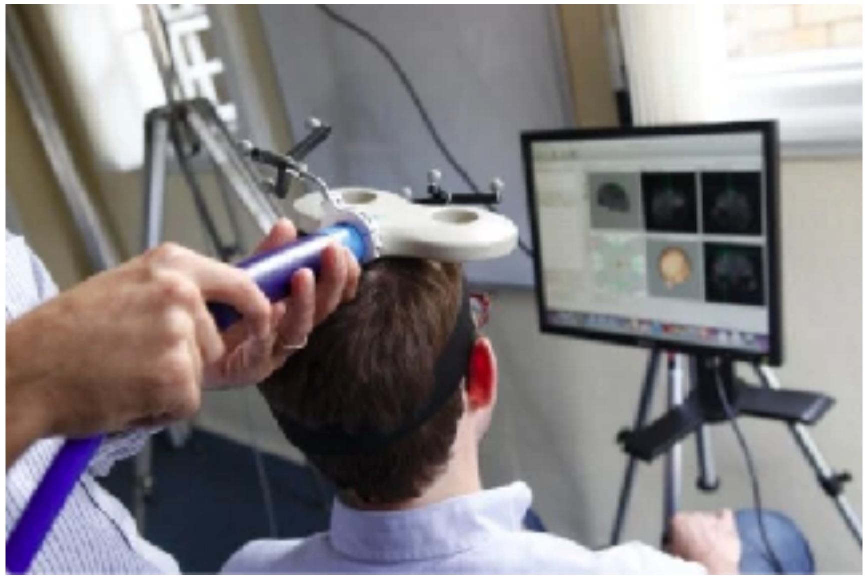
ECoG [4]

Goals:

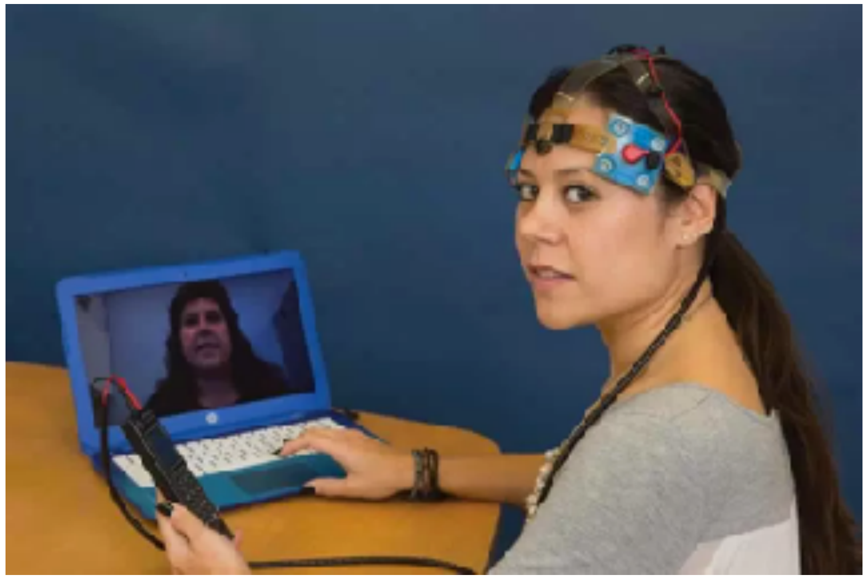
- Understand structure and function of the brain
- Clinical diagnosis
- Mental state detection in real life applications

Image credit: [1]NIH, [2]NIMH, [3]NIRx GmbH, [4]Abel et al., 2014, Physiol Meas

“Writing” the brain



TMS



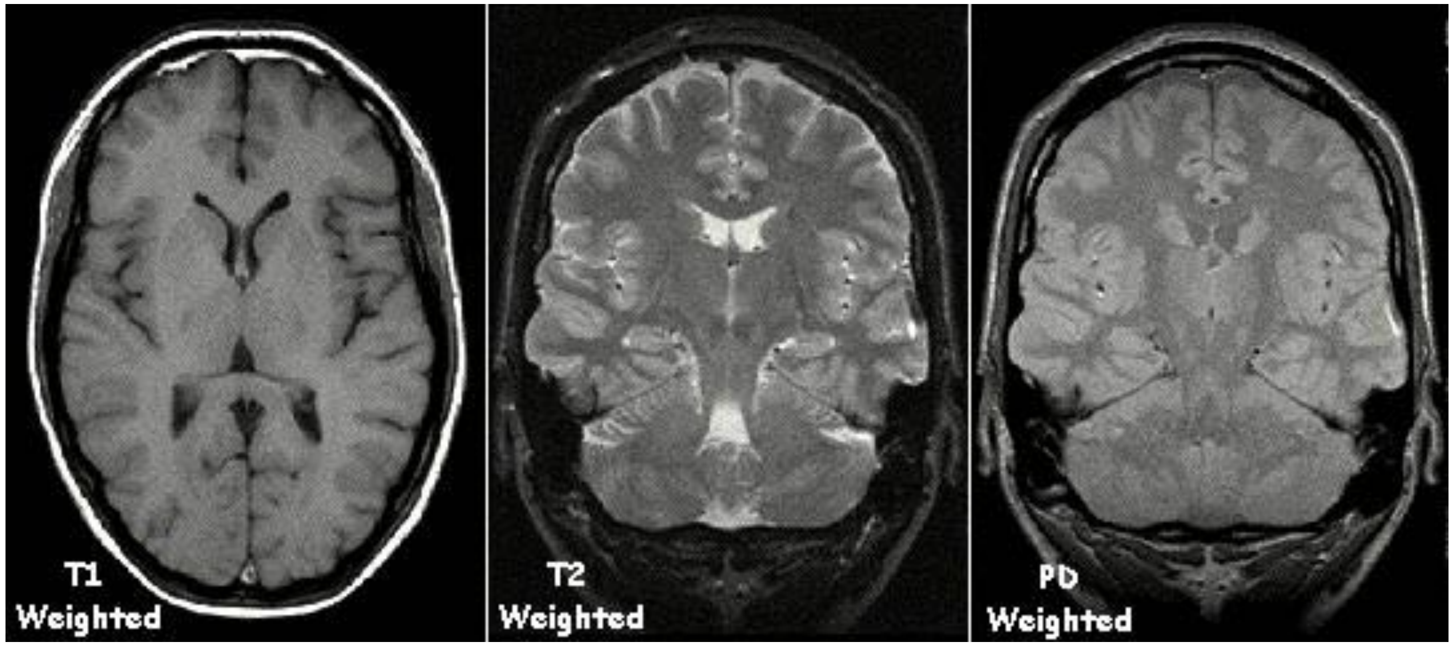
tDCS

DBS

Goal: induce short/long-term changes in brain structure and function

- Neurological and psychiatric diseases
- Cognitive “self-improvement”

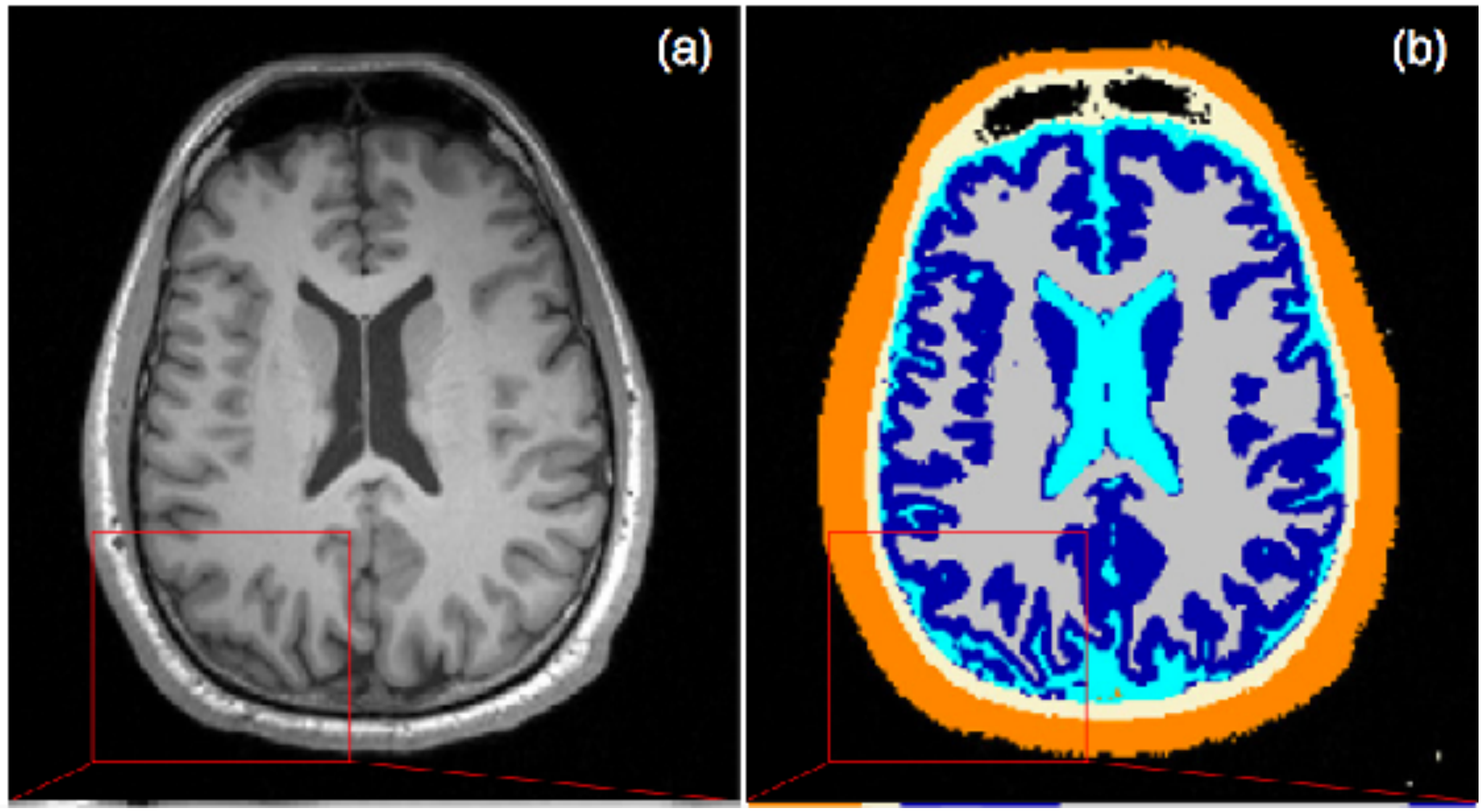
1. Structural MRI



- Physics of image acquisition
- k-space sampling and inverse Fourier transform

2. Segmentation of MR images

Necessary to build anatomical models.

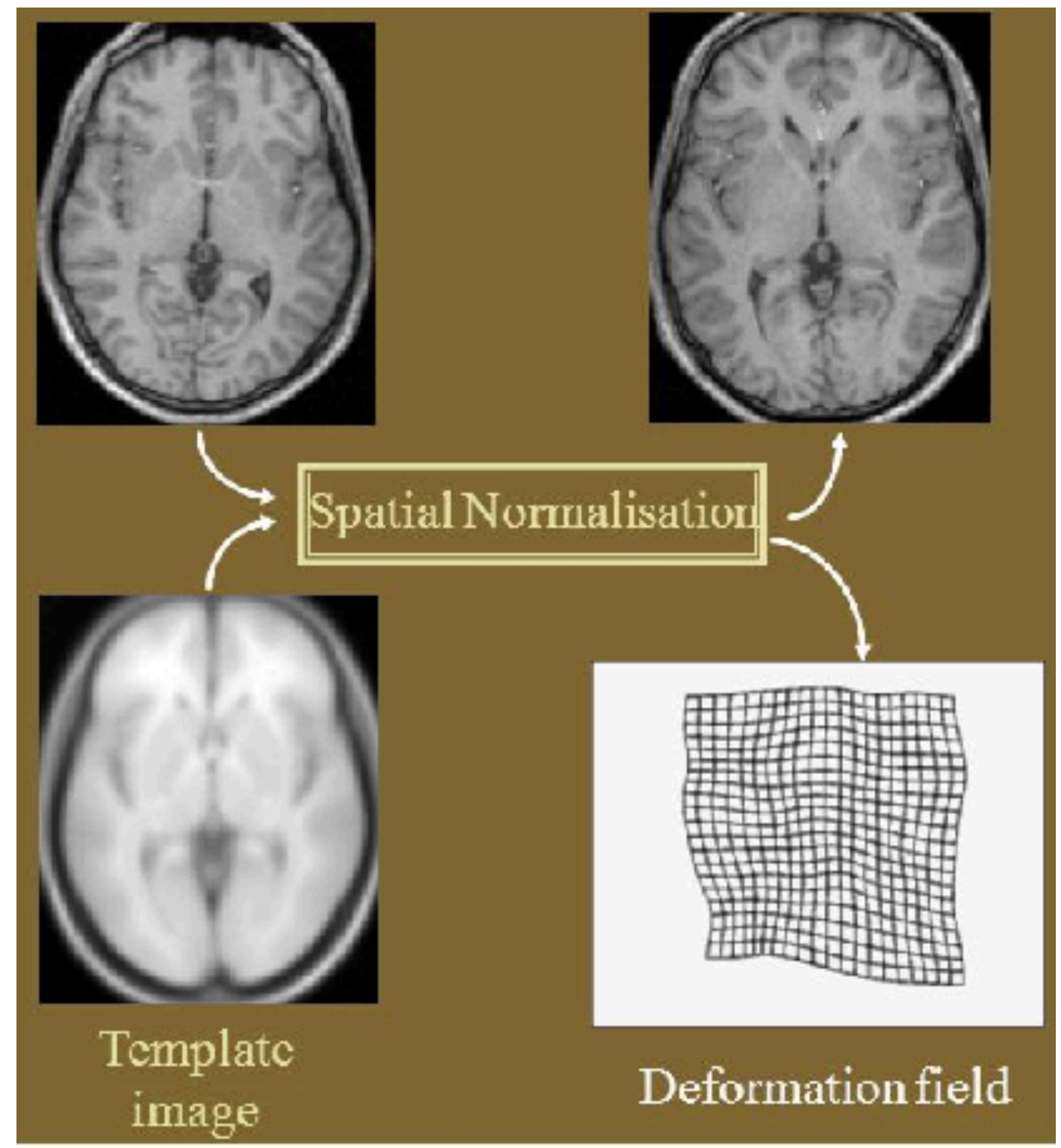


- What algorithms exist and how do they work?

3. Spatial registration of MR images

Necessary

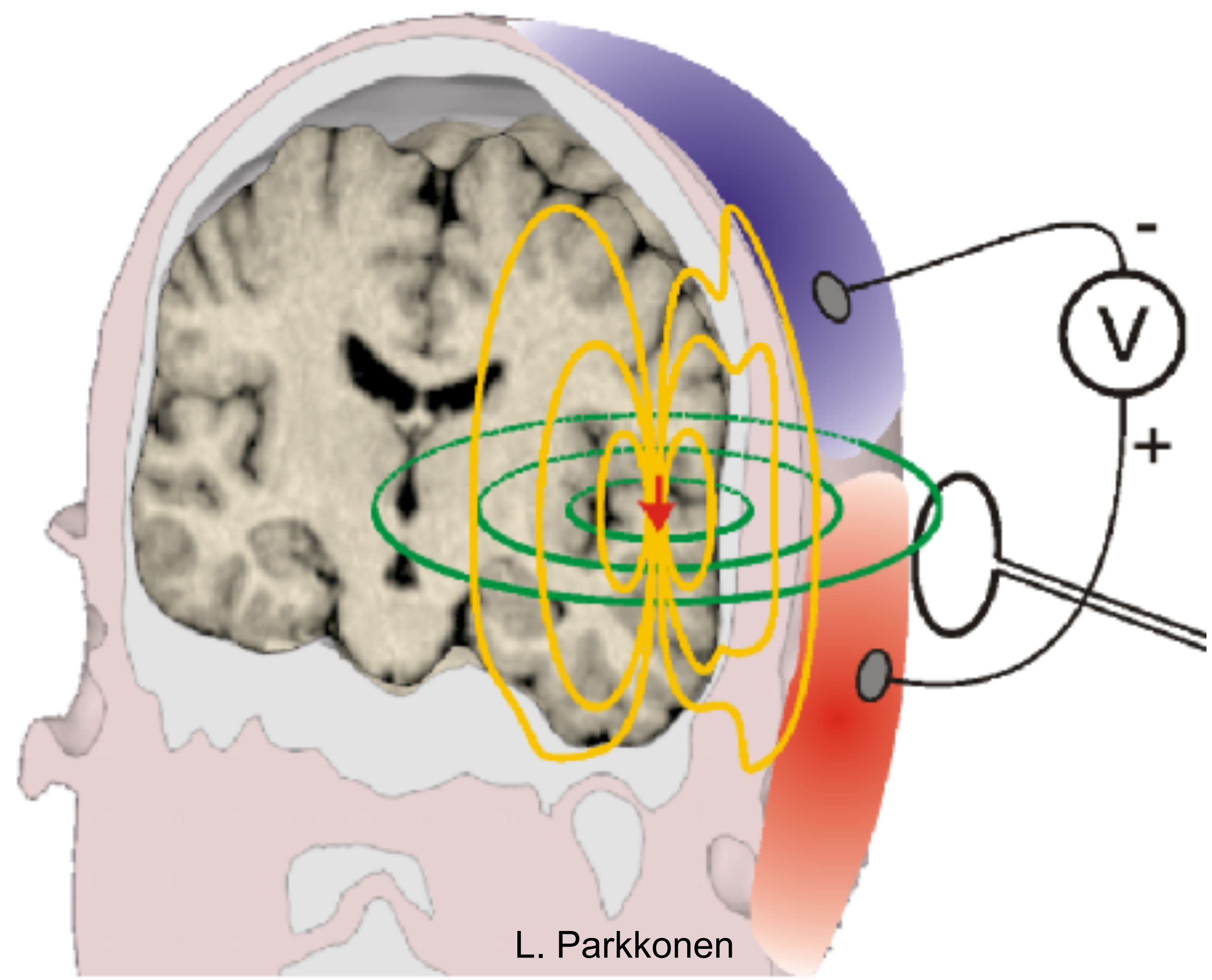
- to perform group analyses
- if no individual anatomical model



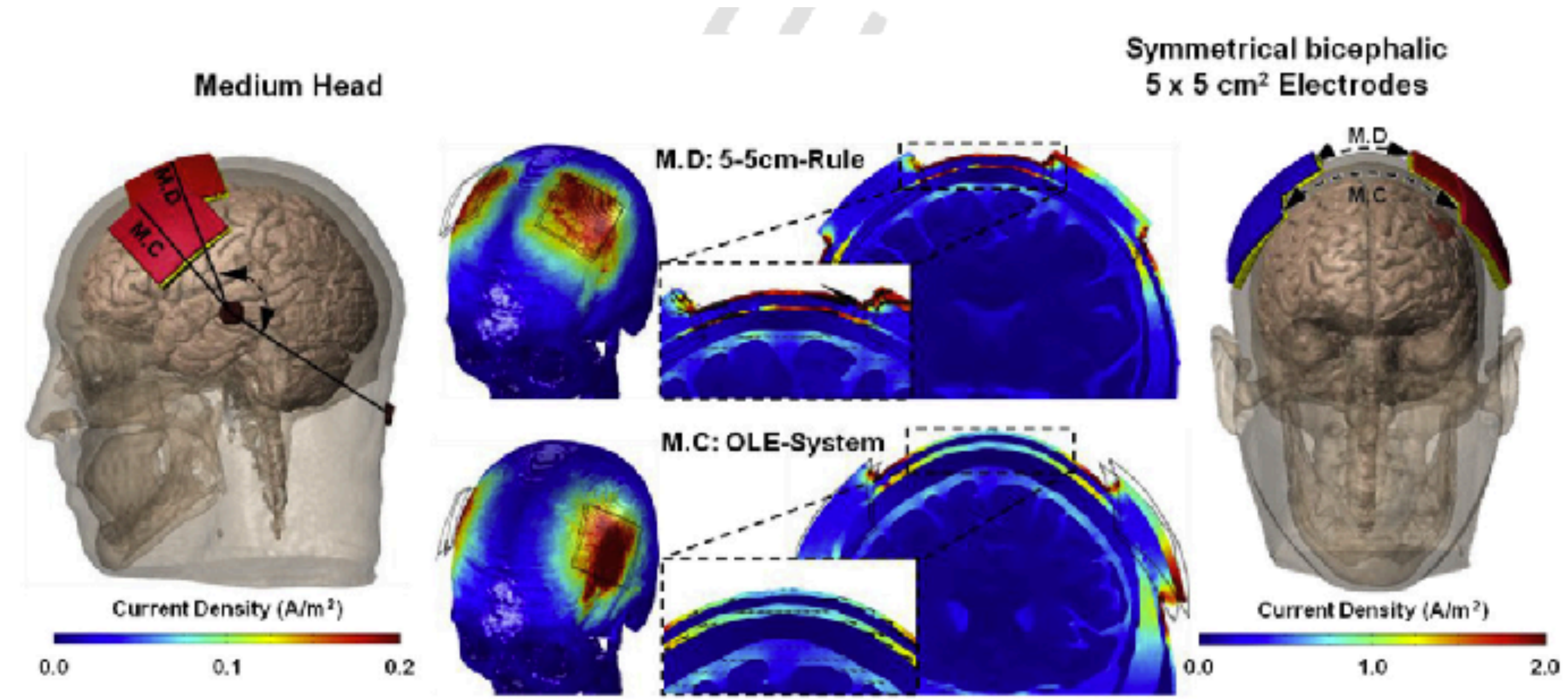
- What algorithms and how do they work?
- Anatomical templates

4. EEG/MEG generation and acquisition

- How does neural activity map to EEG/MEG?
- How can that mapping be computed?



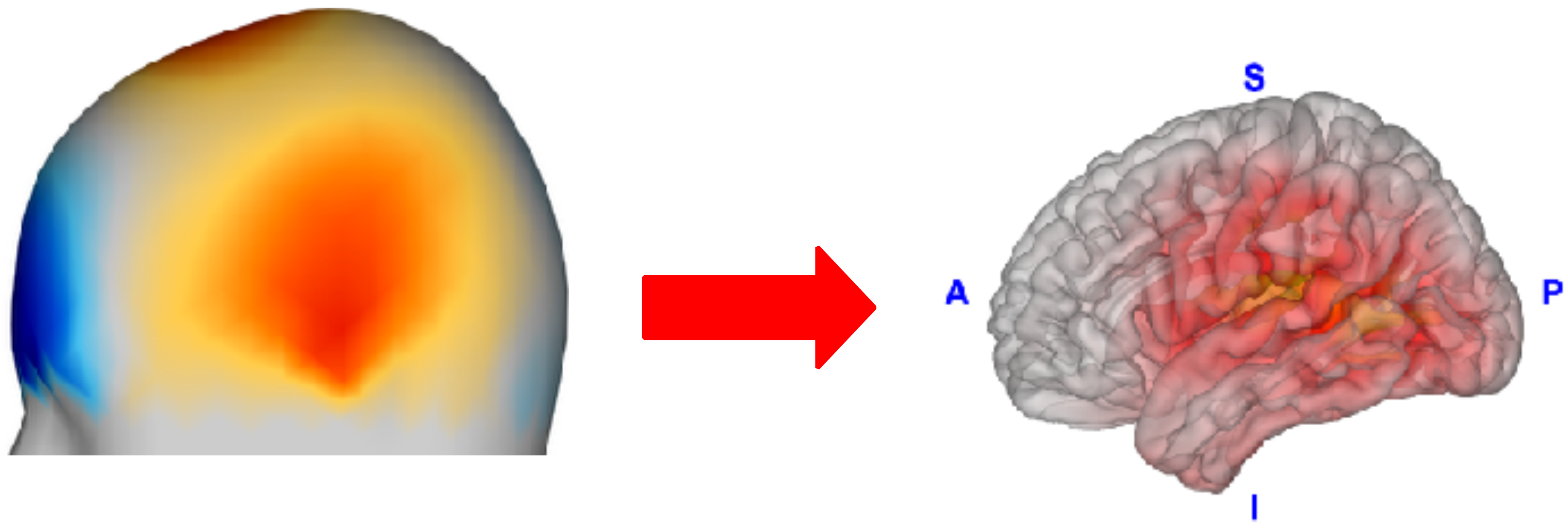
5. Principle of tDCS



- How can the brain current density due to external stimulation be computed?
- What are the claimed physiological effects?

6. EEG/MEG inverse source reconstruction

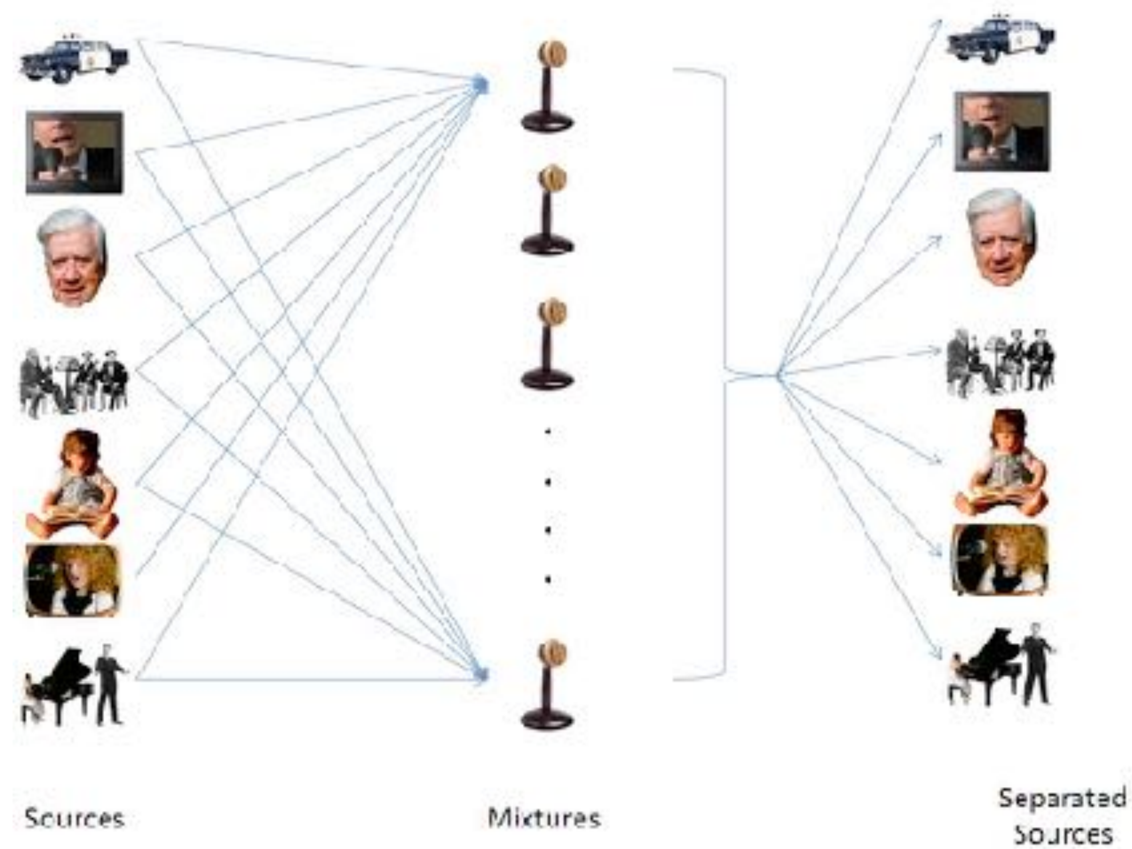
Needed to relate EEG/MEG activity to brain anatomy.



- Ambiguity of the inverse problem.
- What algorithms exist to solve it, how do they work and what are their assumptions.

7. Statistical source separation

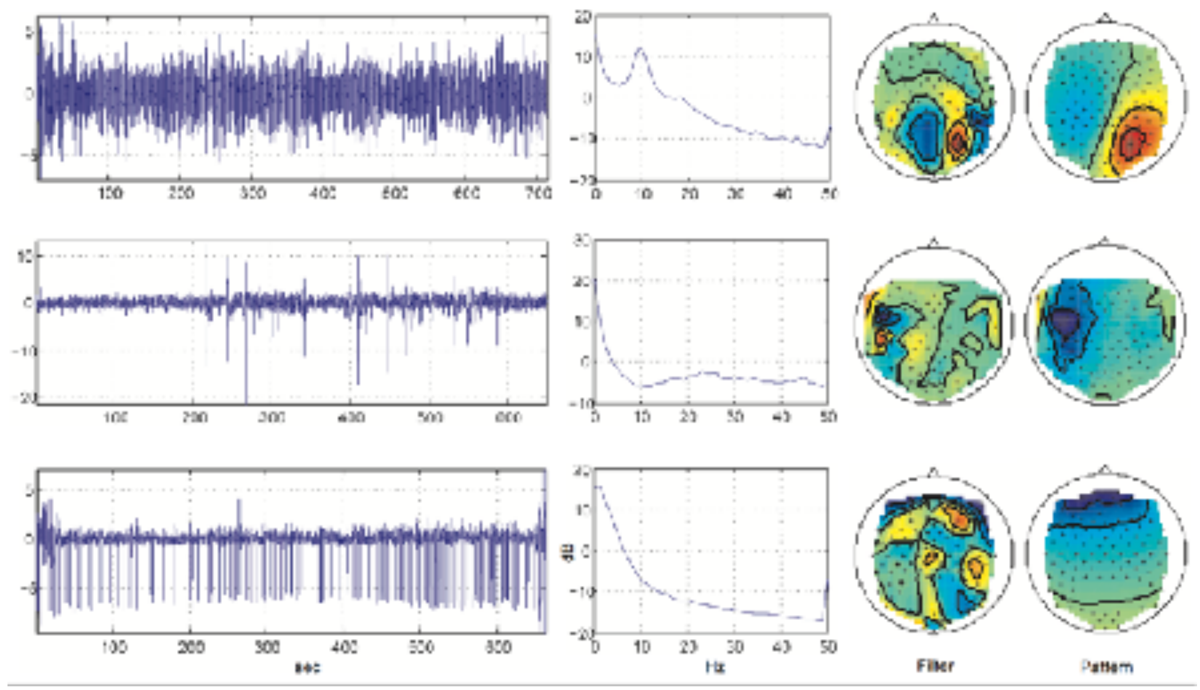
Try to find specific brain sources based on mixed observations based on their statistical properties.



- What assumptions on brain activity are used and what algorithms are optimal under these assumptions.

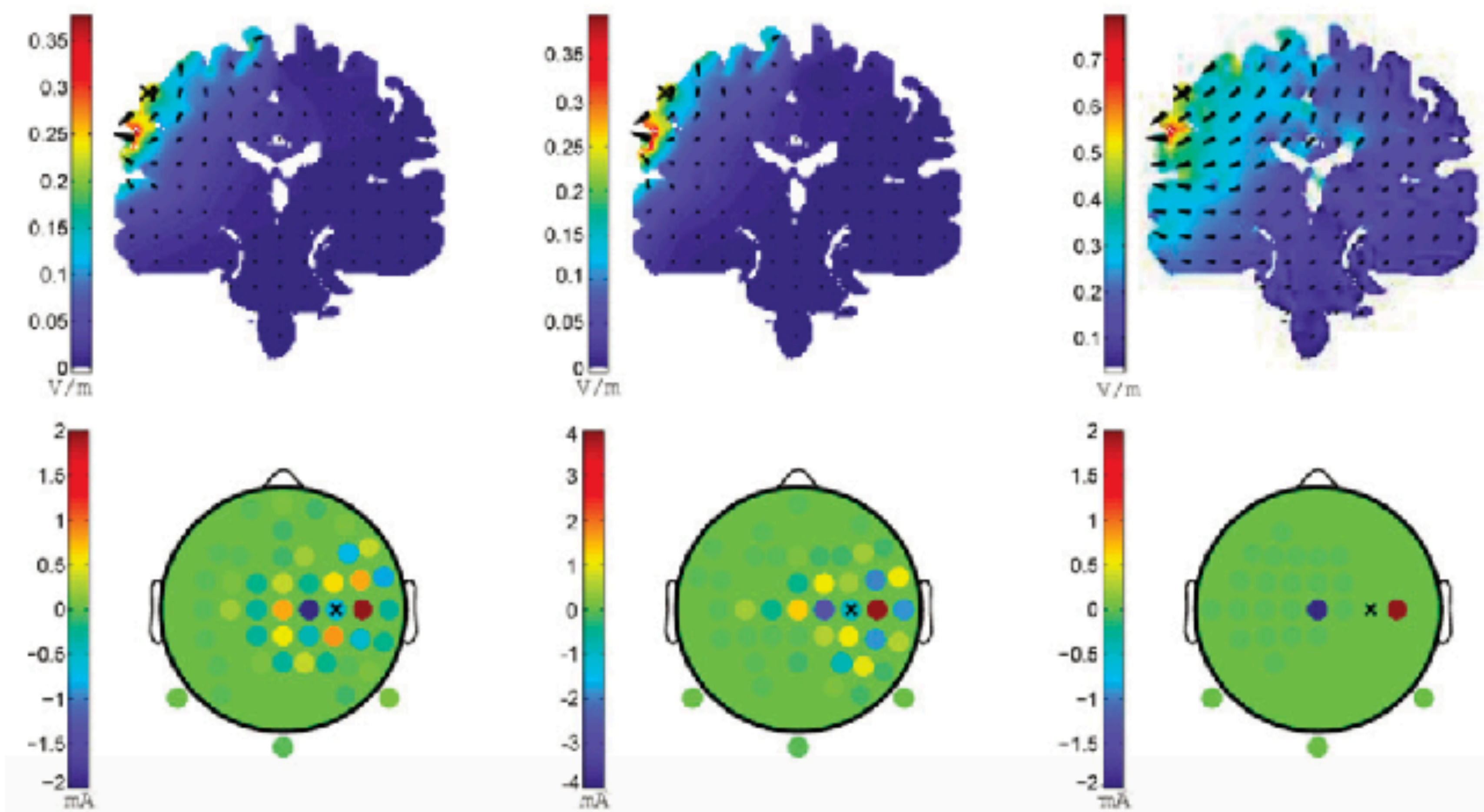
8. Independent component analysis

General-purpose source separation method assuming independent sources.



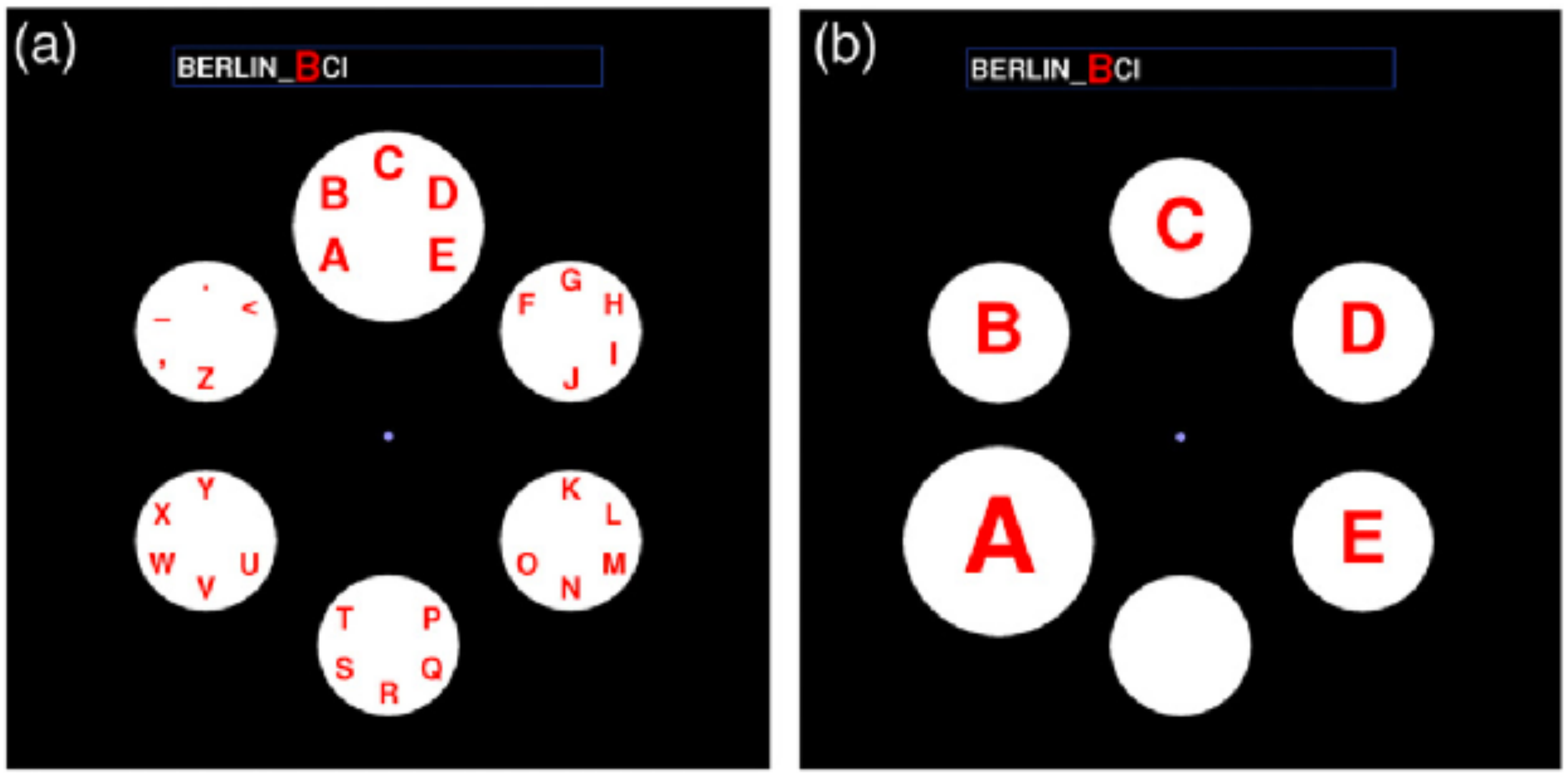
- How can statistical dependence be measured, and what are the corresponding algorithms
- How are different artefacts characterised and how can they be removed using ICA

9. Optimal brain stimulation



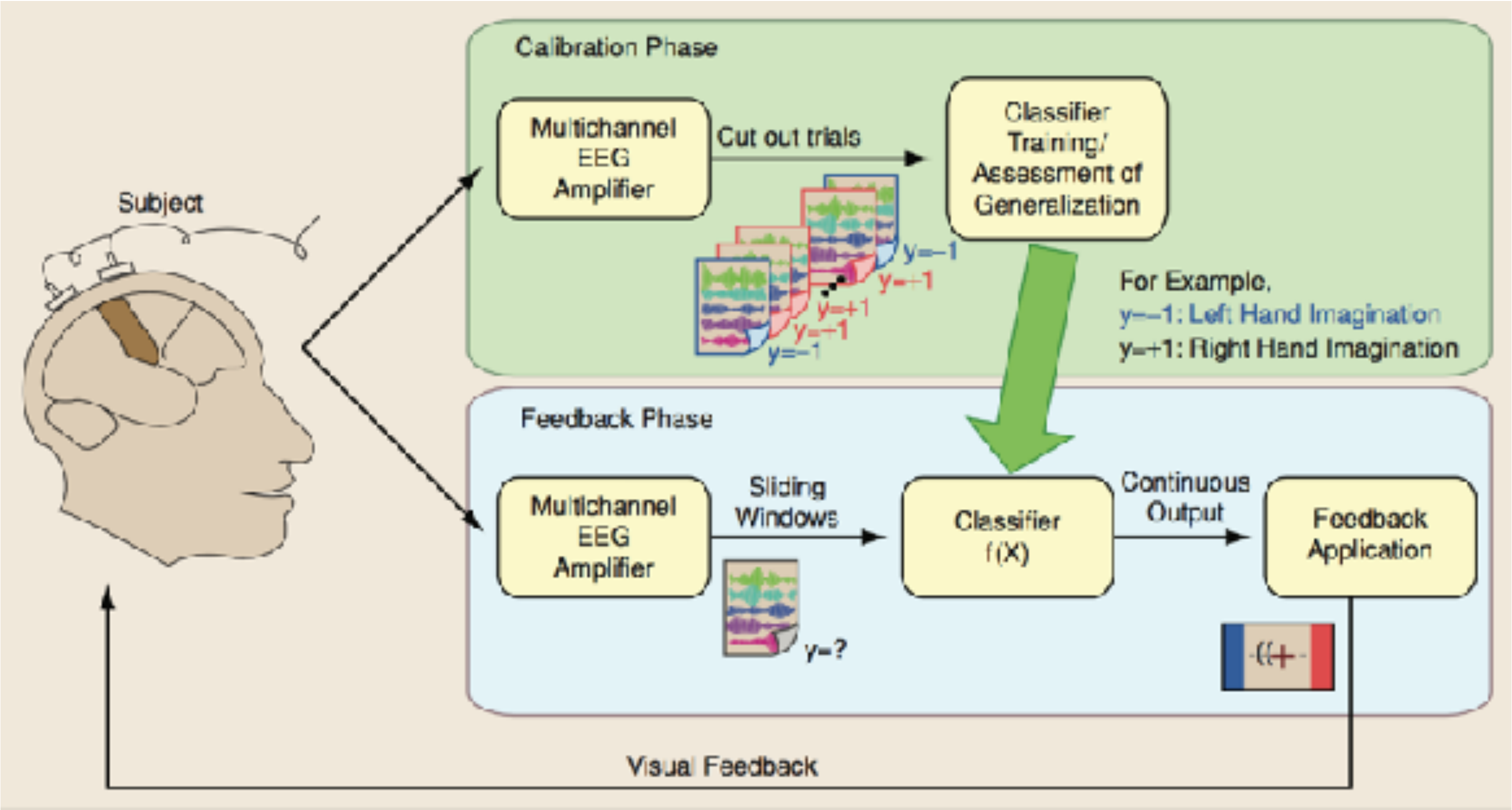
- How can brain stimulation accuracy be improved using optimal stimulation patterns.

10. Brain-computer interfaces based on event-related responses



- What are ERPs and how can they be used to operate a BCI?
- What are the data analysis steps to implement an online ERP-BCI?
- Other applications of ERP: emergency braking intention detection

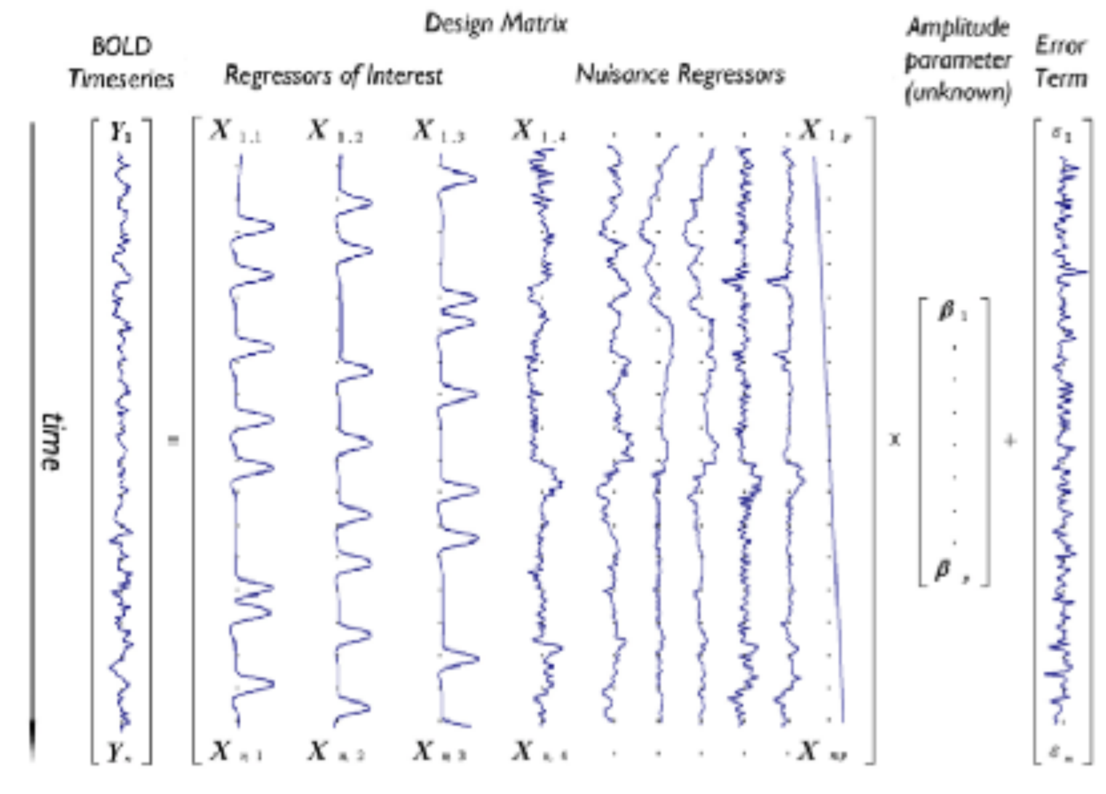
11. BCIs based on brain rhythms

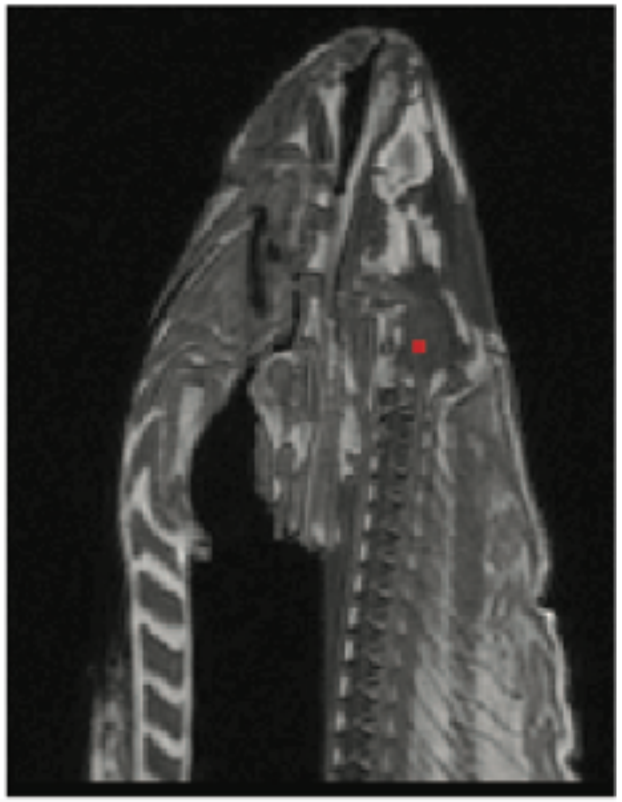


- How does a motor-imagery BCI work and how is it implemented?
- How does an SSVEP-BCI work and how is it implemented?

12. Hierarchical linear models

Classical way to perform statistical inference in fMRI

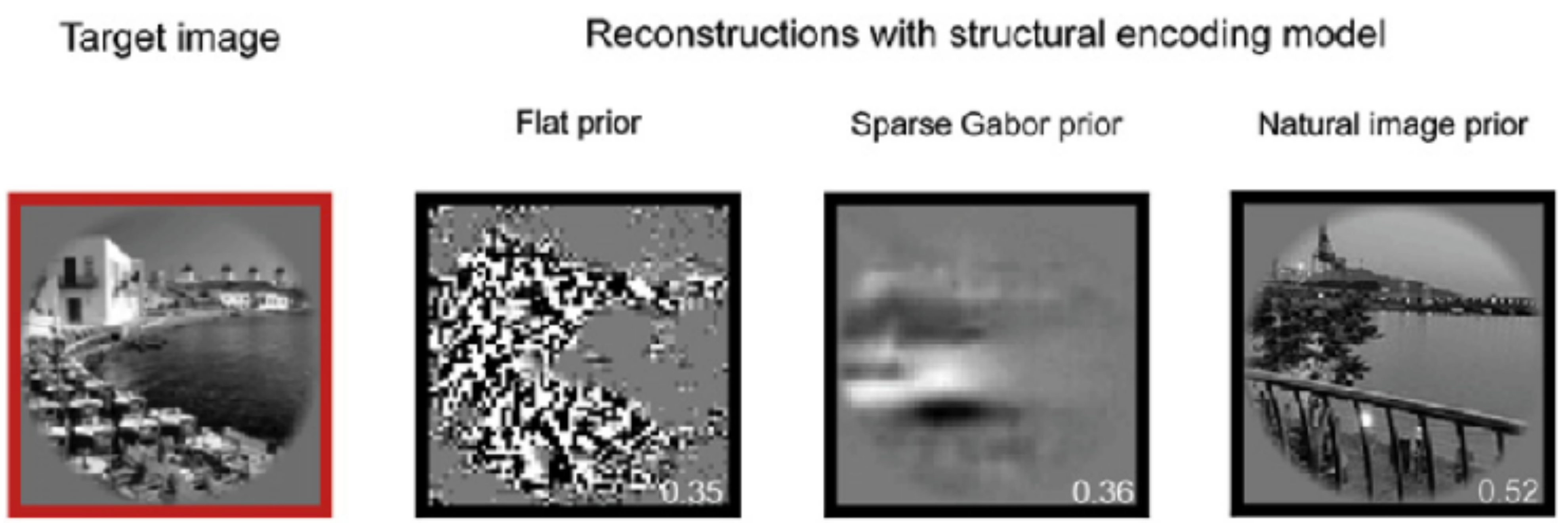




- How to estimate model parameters, how to do inference?
- What are the strengths, weaknesses and potential pitfalls?

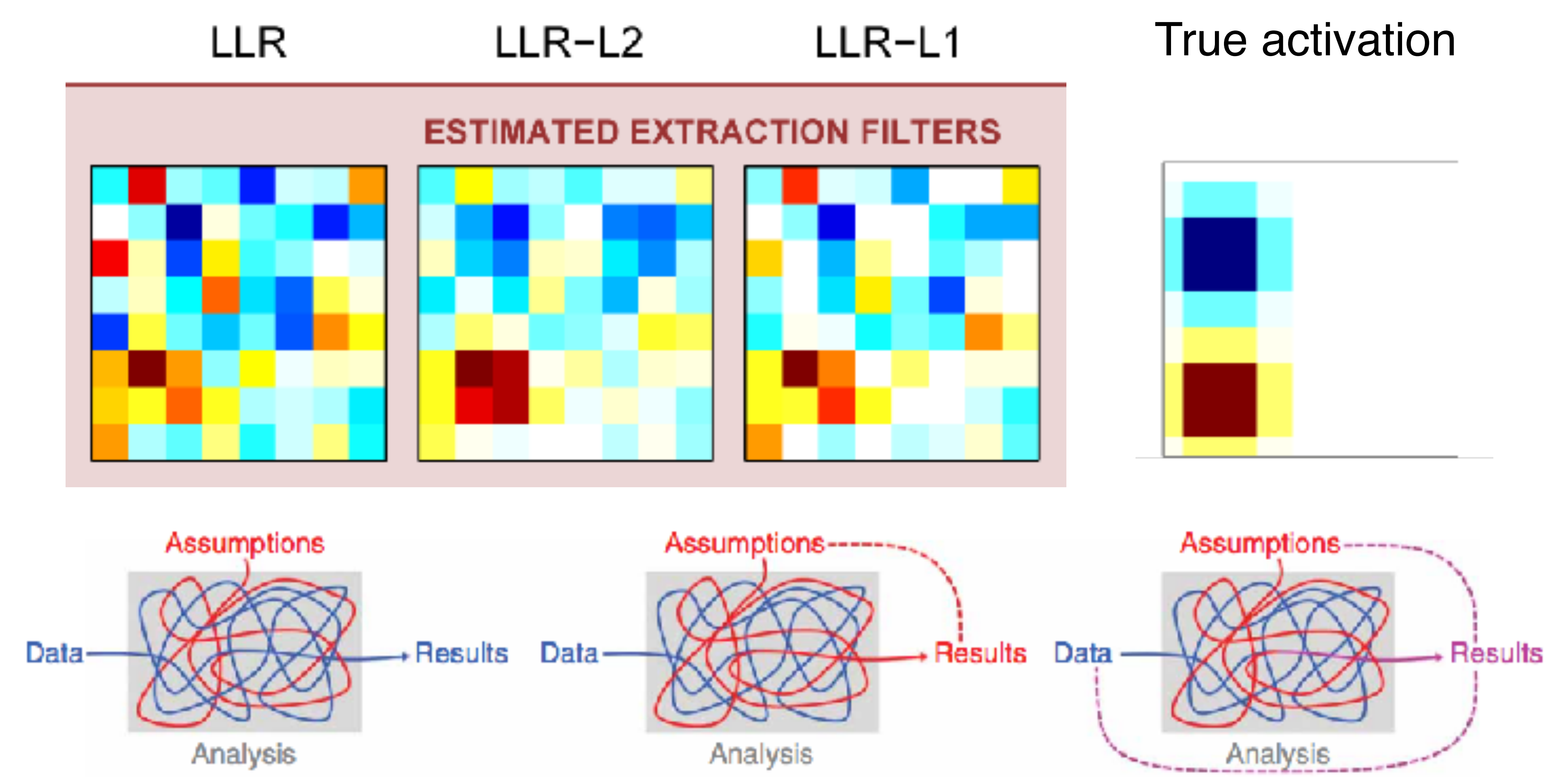
13. Decoding cognitive states using multivariate methods

Multivariate (machine learning) methods enable predictions, not than just significant tests.



- Overview of some famous fMRI studies and what their analysis logic is.

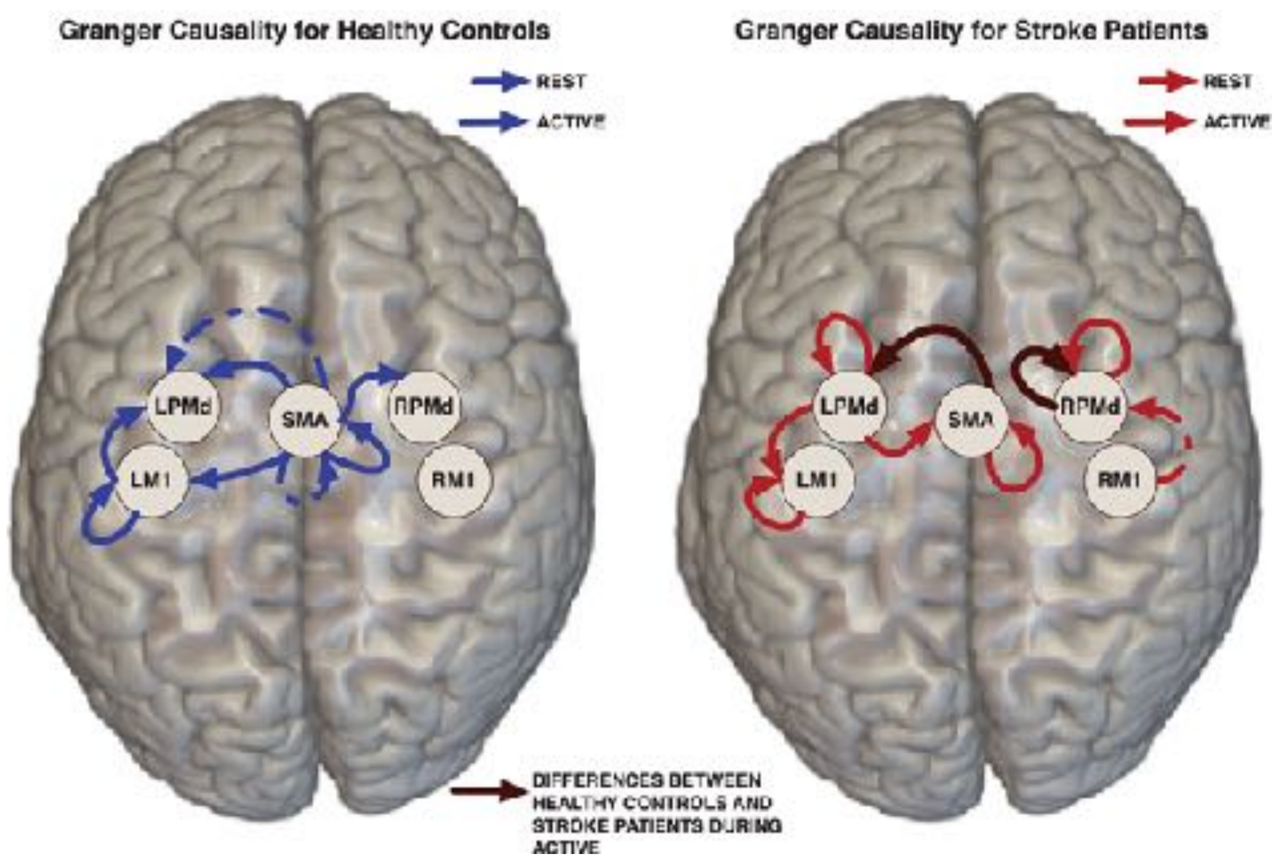
14. Pitfalls in machine learning for neuroimaging



- Discussion of pitfalls and how to avoid them.

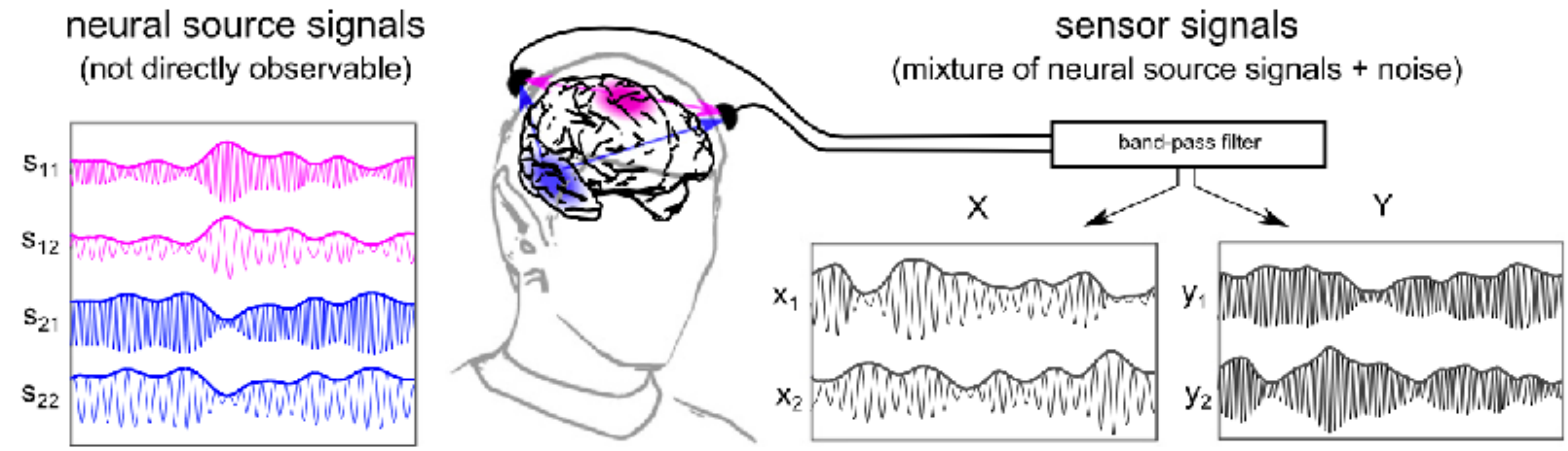
15. Brain connectivity analysis in EEG/MEG

High time resolution allows to study interactions between brain signals.



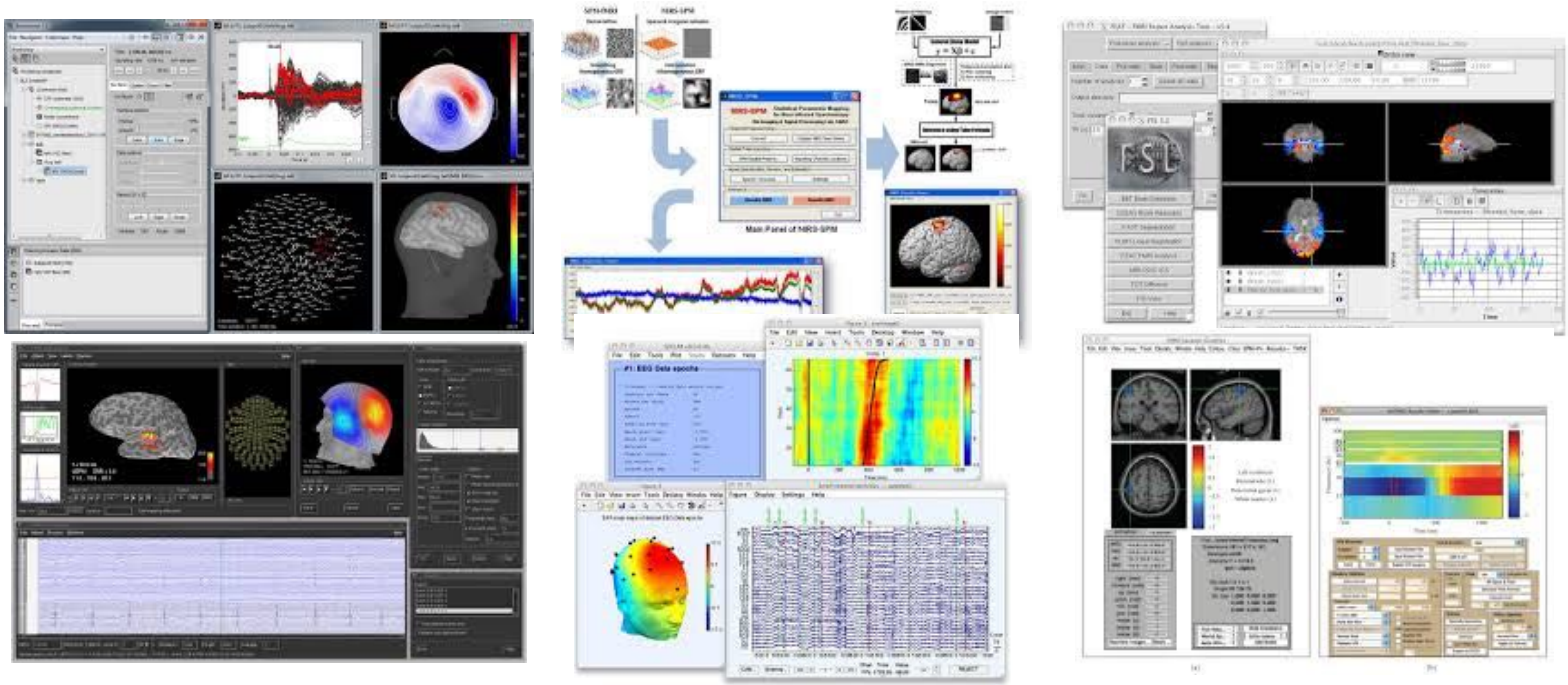
- How to avoid spurious connectivity in the presence of mixed signals and correlated noise?

16. Decomposition methods for interacting sources



- Algorithms to find brain sources with specific types of interactions.

17. Toolboxes



- What open toolboxes are there, and what can you do with them?

Procedure

- Download material from goo.gl/HcAgVB
- Send me an email with a ranked list of four preferred topics:
  stefan.haufe@tu-berlin.de
- I will assign topics trying to find the best global solution
- Arrange a meeting with me to discuss content of your talk
- Ideally send me your slides one week before seminar
- Seminar takes place
    - Feb 26th 9-18 hrs, room MAR 4.033
    - Additionally on Feb 27th OR 28th