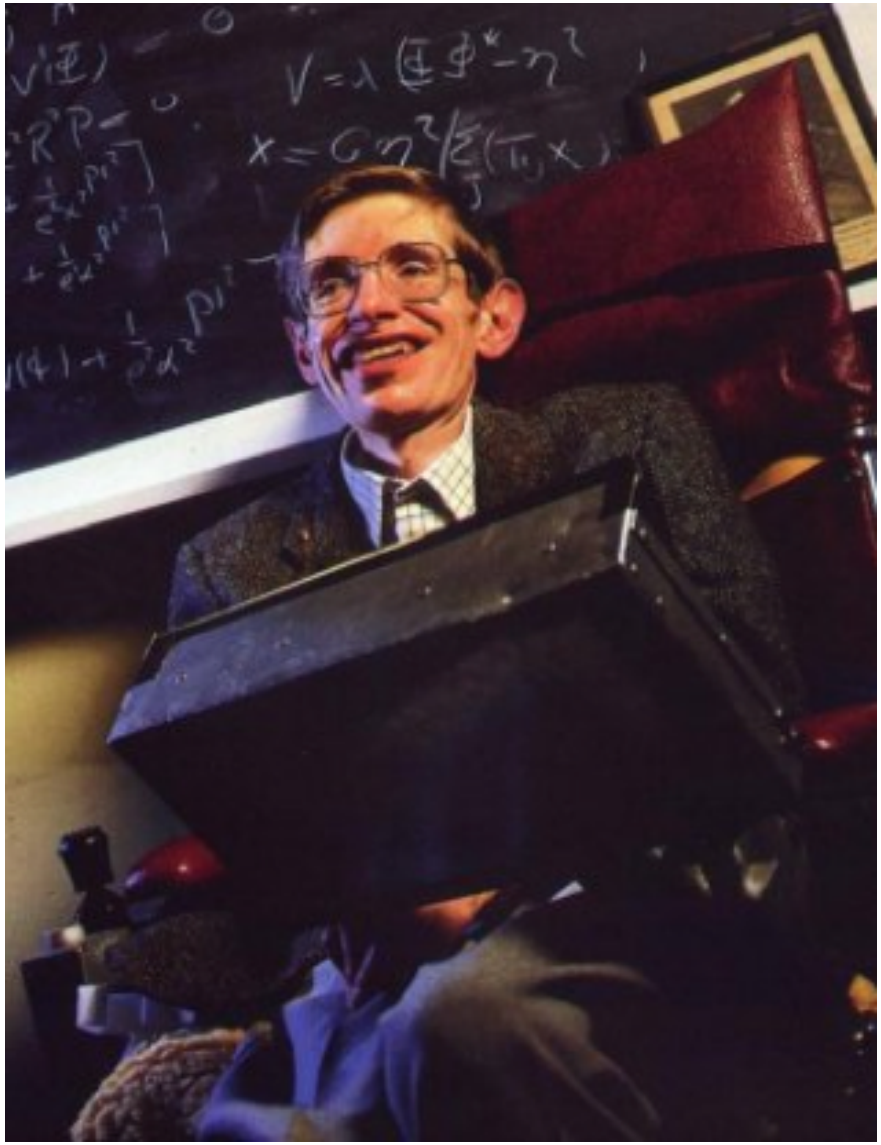
Thinking Out Loud:

Research and Development of Brain–Computer Interfaces

N. Jeremy Hill

Max Planck Institute for Biological Cybernetics, Tübingen, Germany

Stephen Hawking (1942—)



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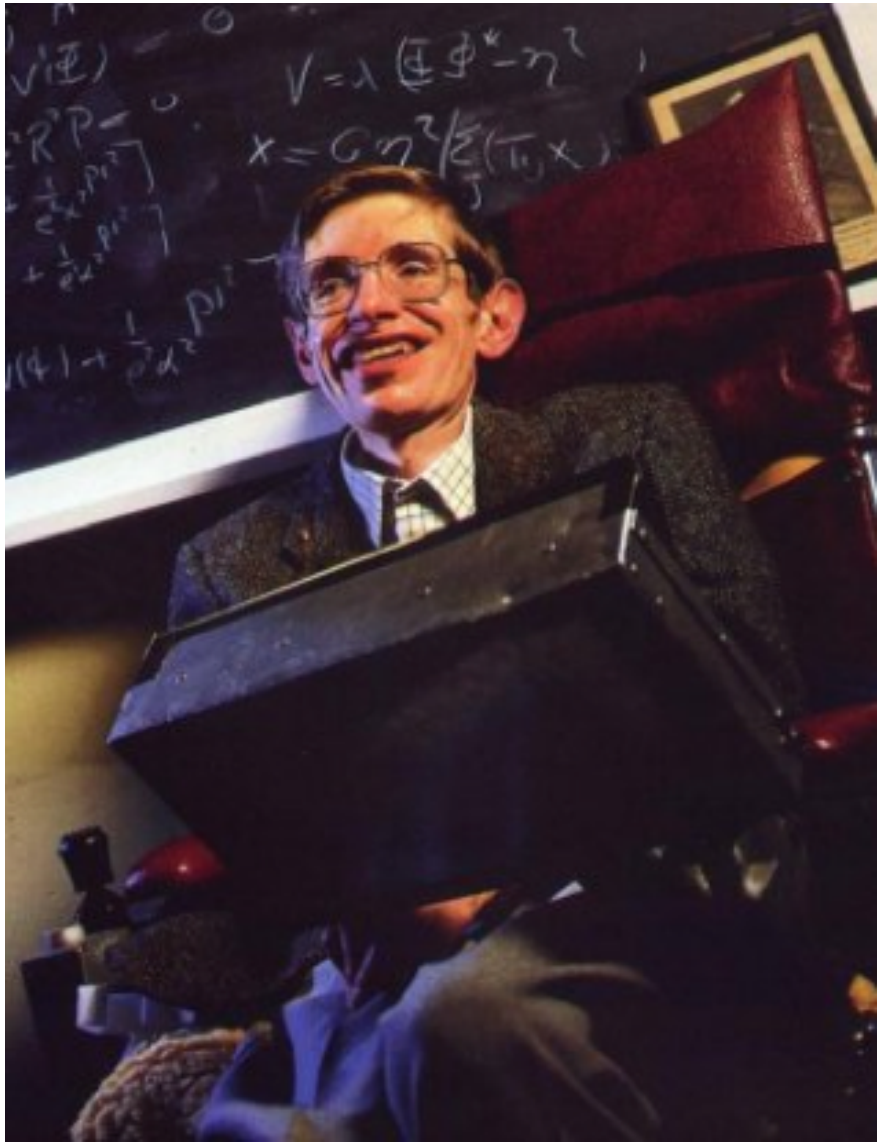

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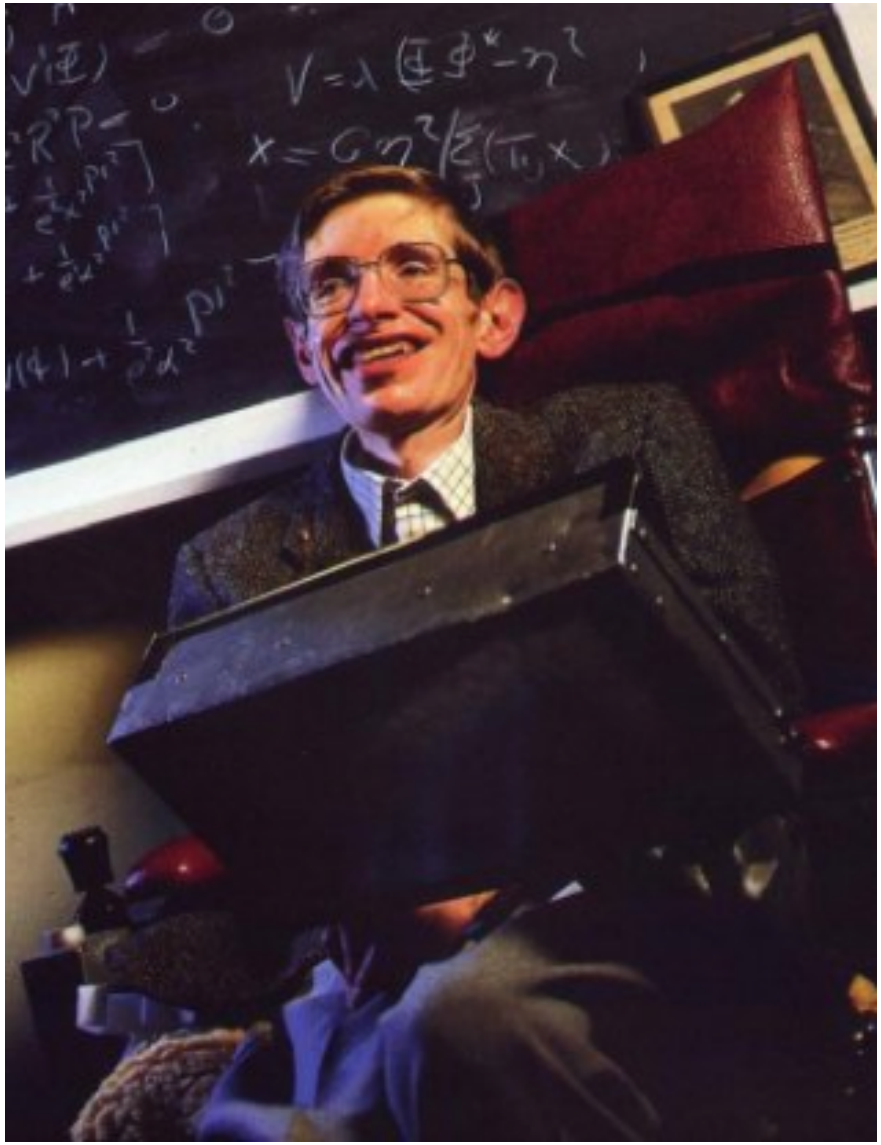

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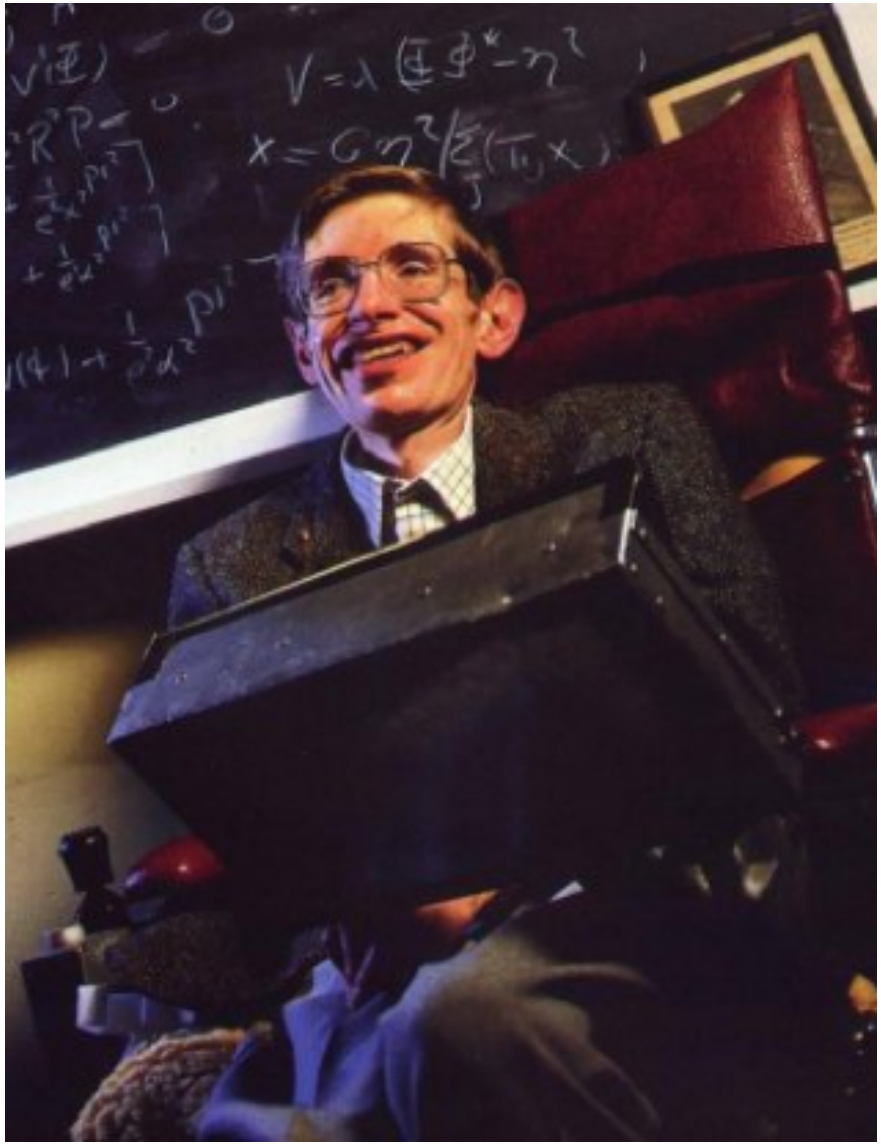

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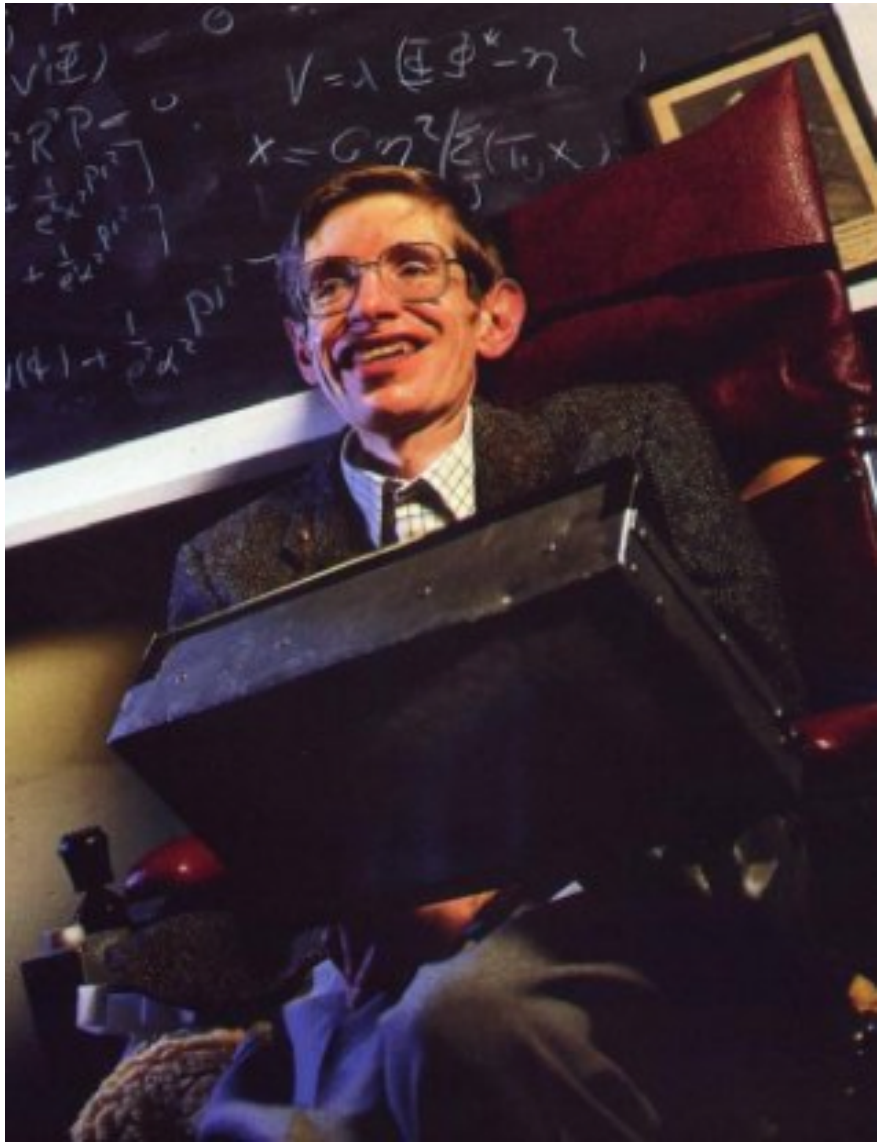

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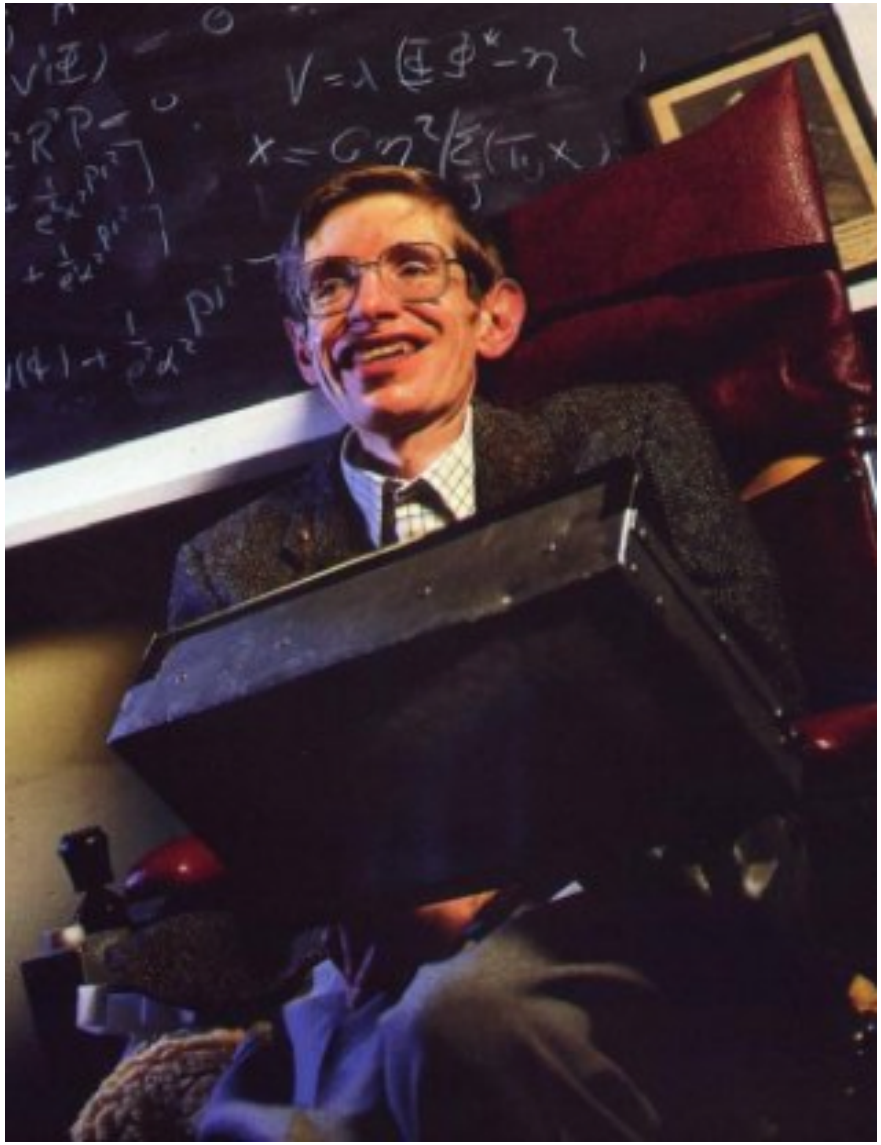

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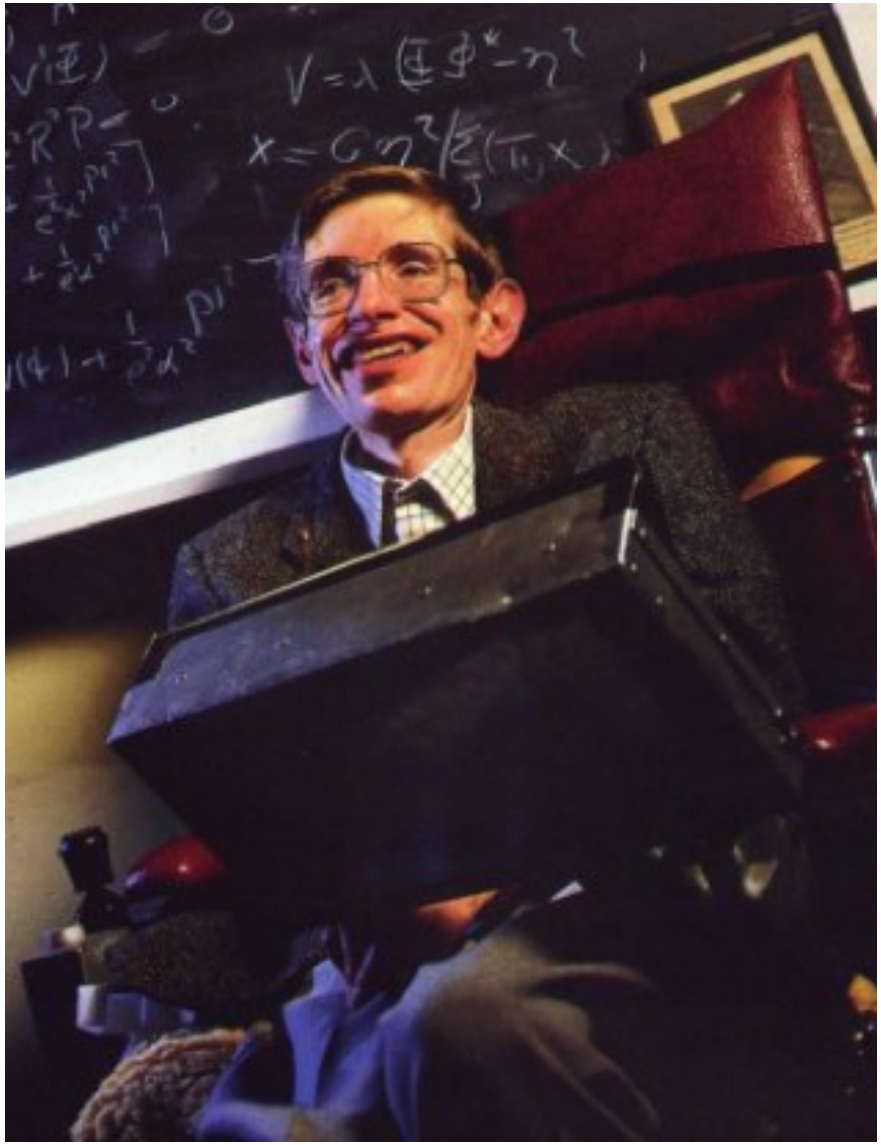

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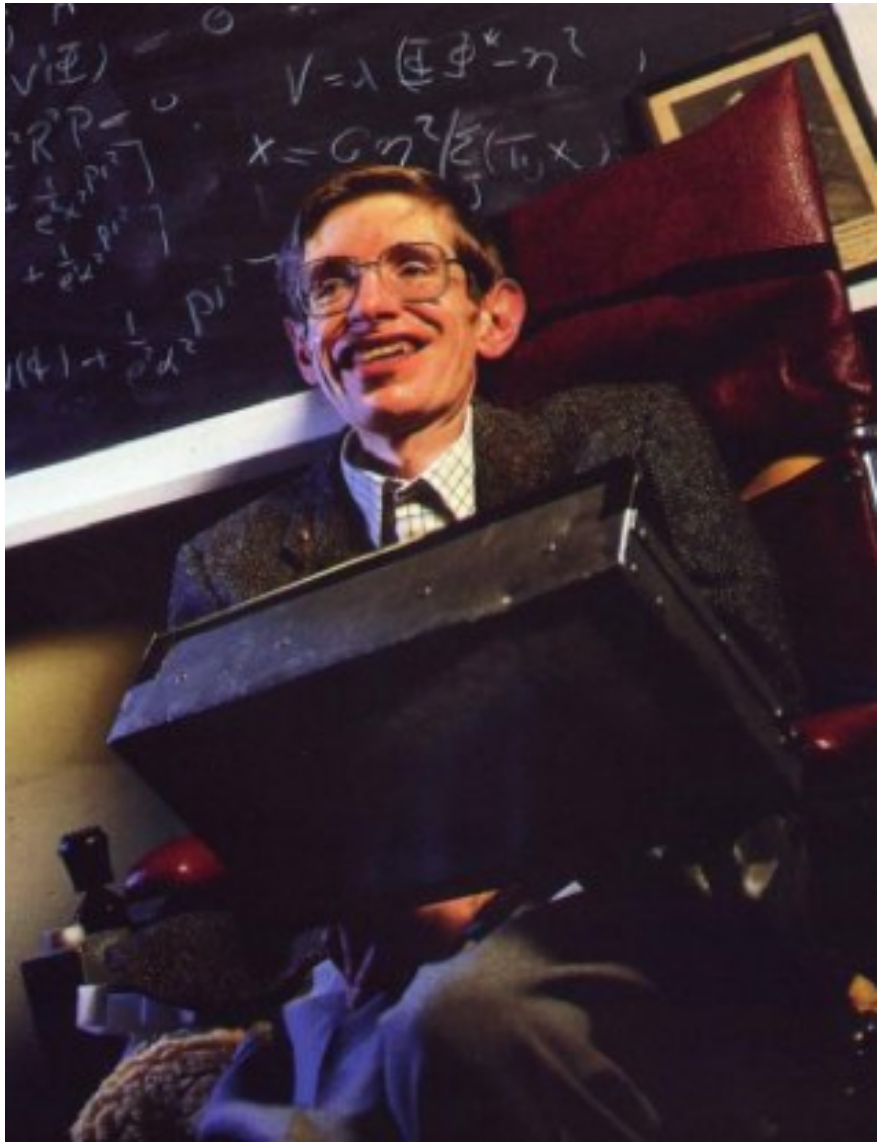

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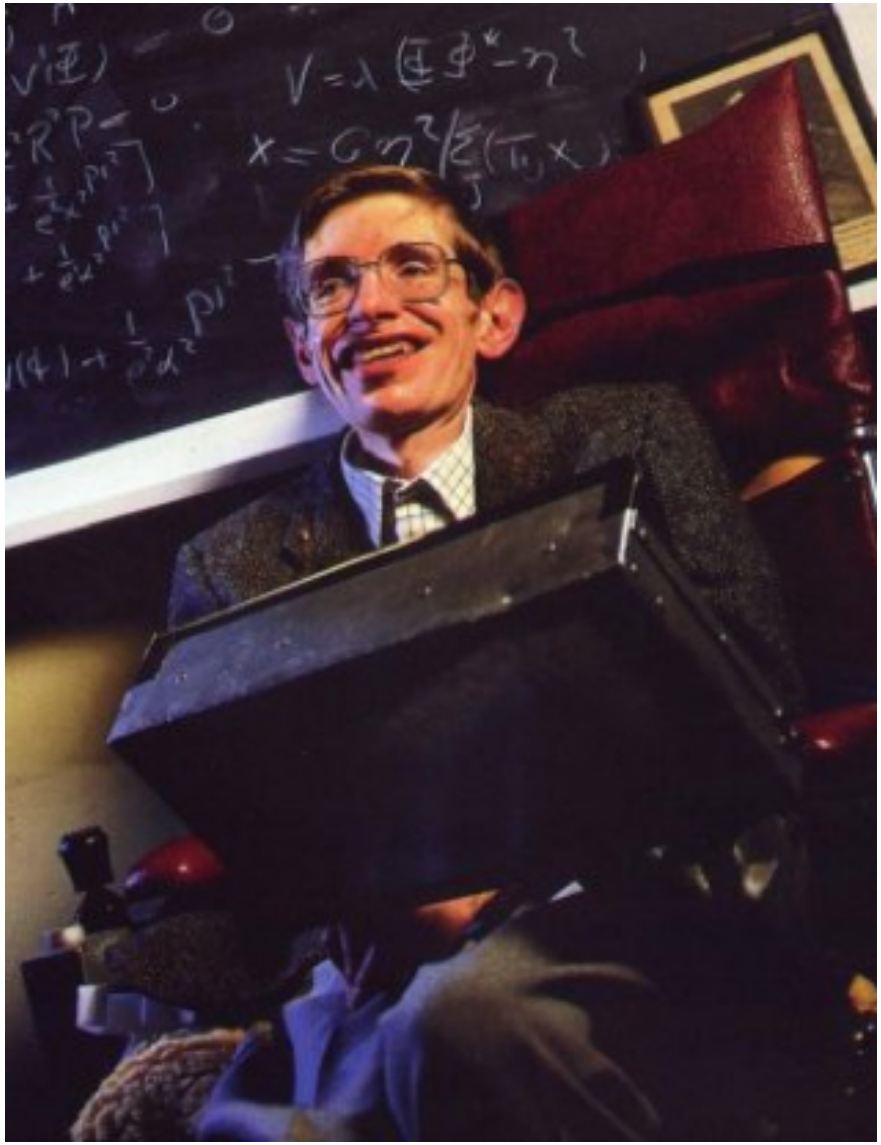
. . . despite having Amyotrophic Lateral Sclerosis (ALS) since age 21.



The Locked-In State

- Brainstem stroke
- Guillan-Barré Syndrome
- Multiple Sclerosis
- Cerebral Palsy
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can lead to

- Locked-In Syndrome (LIS): quadriplegia + inability to speak
- "Completely Locked-In" Syndrome (CLIS): complete inability to communicate due to lack of voluntary muscle control, despite intact cognitive functions

ALS

Amyotrophic Lateral Sclerosis (aka Lou Gehrig's disease / Maladie de Charcot)

- is a progressive degeneration of motor neurons;
- has no known cure;
- is inherited in 10% of cases, sporadic in 90%;
- typically leads to CLIS within 2–5 years;
- is not fatal per se (if artificial ventilation is provided after breathing fails);
- causes (directly) relatively little cognitive degeneration (maybe none?).

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- Worldwide incidence is 120,000 diagnoses per year (2 per 100,000).*
- Worldwide prevalence is 400,000 at any one time (6 per 100,000).*
- Frequency is roughly 1/10 that of Multiple Sclerosis.
- est. 8000 cases in Germany today (based on US prevalence of 10 per 100,000).

*source: "International Alliance of ALS/MND Associations on the Internet" July 2007
`http://www.alsmndalliance.org/whatis.html`

Measuring Brain Activity

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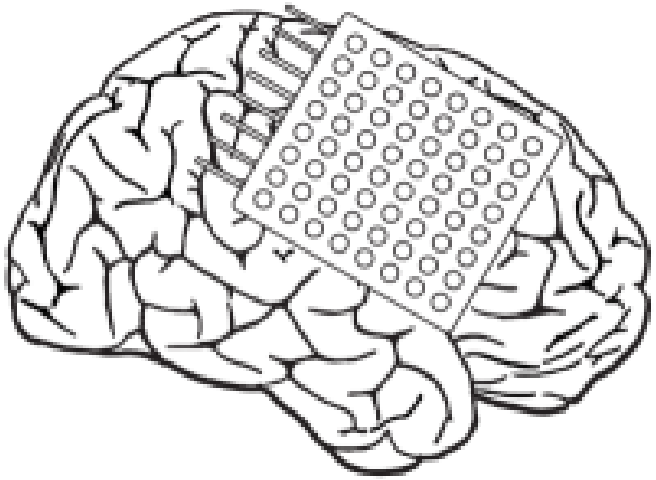
Electroencephalography (EEG)

Measuring Brain Activity

Department of Epileptology,

University of Bonn, 2004



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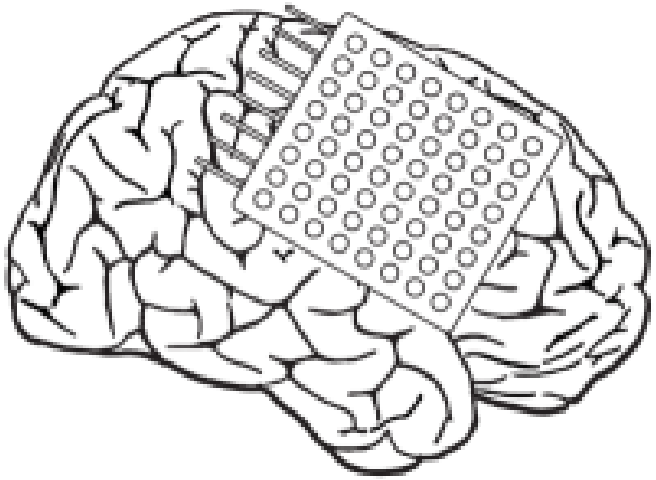

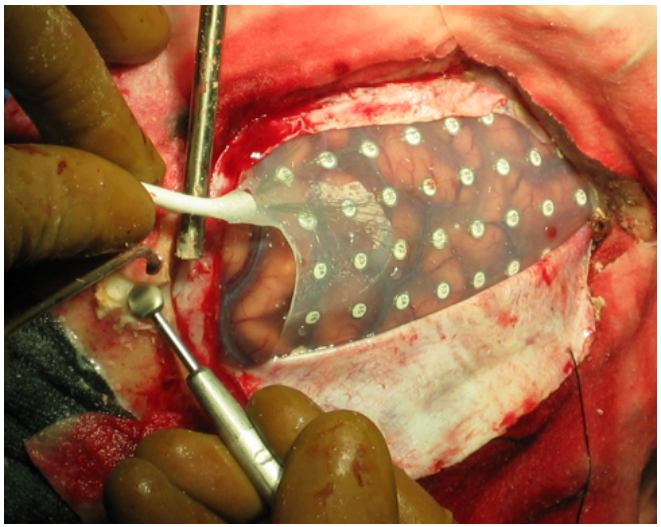

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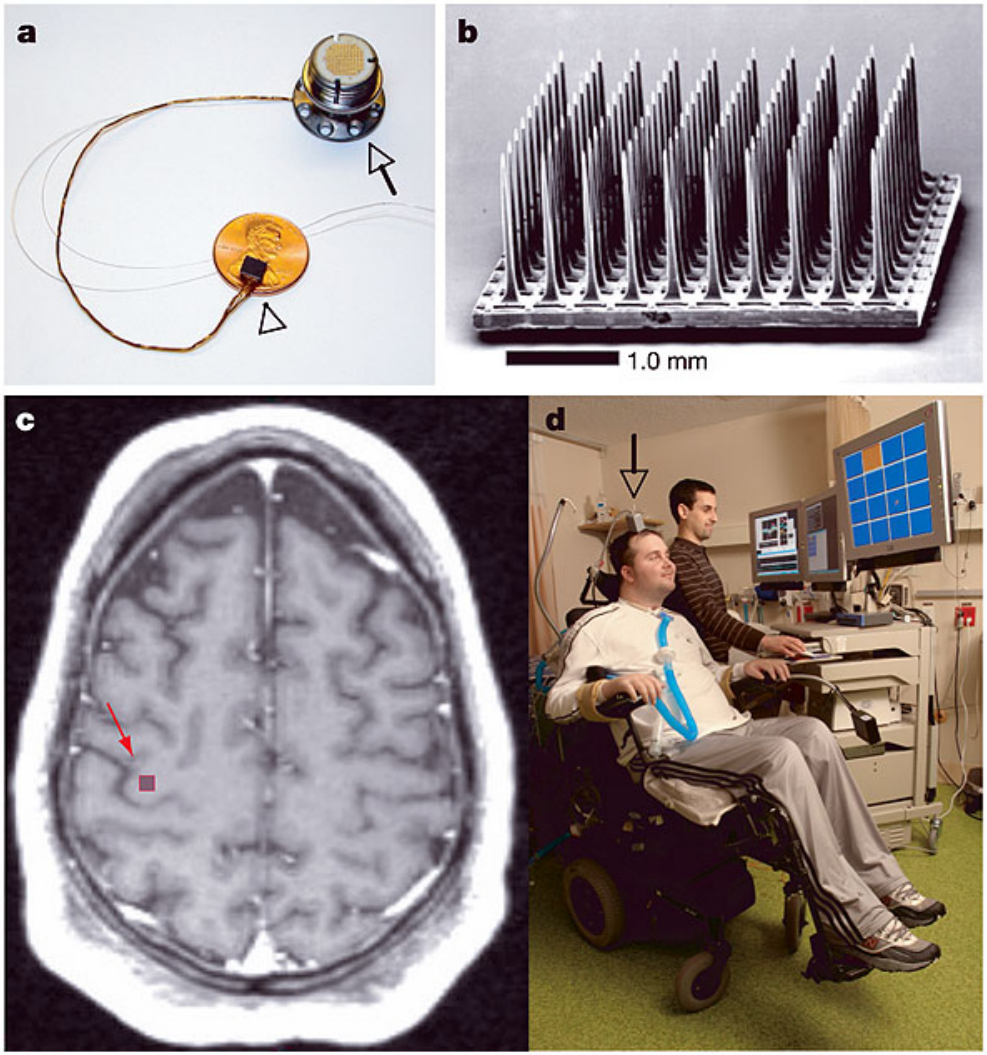

Implanted
microelectrode array
(Cyberkinetics, Inc)

Figure from
Hochberg et al.
Nature, July 2006.

Measuring Brain Activity

Near Infra-Red Spectrophotometry (NIRS)

Measuring Brain Activity

Magnetoencephalography (MEG)

Functional Magnetic Resonance Imaging (fMRI)

Letter from a Locked-In User

LIEBER-HERR-BIRBAUMER-
HOFFENTLICH-KOMMEN-SIE-MICH-BESUCHEN,-WENN-DIESER-
BRIEF-SIE-ERREICHT-HAT-.ICH-DANKE-IHNEN-UND-IHREM-TEAM-
UND-BESONDERS-FRAU-KÜBLER-SEHR-HERZLICH,-DENN-SIE-
ALLE-HABEN-MICH-ZUM-ABC-SCHÜTZEN-GEMACHT,-DER-OFT-
DIE-RICHTIGEN-BUCHSTABEN-TRIFFT.FRAU-KÜBLER-IST-EINE-
MOTIVATIONSKÜNSTLERIN.OHNE-SIE-WÄRE-DIESER-BRIEF-
NICHT-ZUSTANDE-GEKOMMEN.-ER-MUSS-GEFEIERT-WERDEN.-
DAZU-MÖCHTE-ICH-SIE-UND-IHR-TEAM-HERZLICH-EINLADEN-.
EINE-GELEGENHEIT-FINDET-SICH-HOFFENTLICH-BALD.

MIT-BESTEN-GRÜSSEN-IHR-
(vollständiger Name des Patienten)

Birbaumer et al., Nature, March 1999.

Other potential users

Brain-Computer Interface (BCI) technology also has potential value for

- people with spinal-cord lesions
- stroke recovery
- neurofeedback (as therapy for ADHD, depression, anxiety, . . .)
- any user who needs an “extra hand” (e.g. astronauts wearing pressurized gloves)
- anybody (computer games)

Video from Cyberkinetics, Inc

Room for Improvement

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- voice-recognition systems
- shoulder joysticks
- tongue joysticks
- eyetrackers
- head pointers
- sip-and-puff switches
- blink switches
- ...
- human interaction

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... where the user is able to use them.

Room for Improvement

Our goals are:

- develop BCIs as a useful complement to other technologies;
- improve current BCIs until they are better than the other technologies;
- make BCIs work for users who have no other options.

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There has not yet been a convincing, successful case of communication by a "completely locked-in" user.

Challenges

- Induction
- Measurement
- Decoding
- Integration

Challenges

- **Induction**
- Measurement
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Induction methods:

- learn to self-regulate cortical DC potential;
- focus attention on one of a set of concurrent stimuli;
- imagine moving parts of the body;
- imagine something else (mental arithmetic, mental rotation, ...).

Challenges

- Induction
- **Measurement**
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Measurement

- EEG, NIRS
- ECoG, micro-electrode
- other future technology...

Challenges

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- **Decoding**
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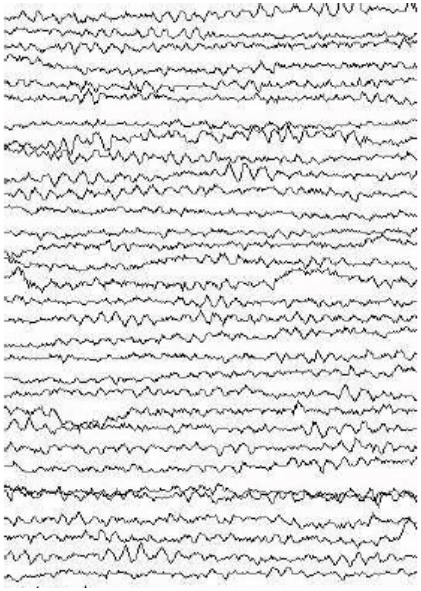

$$\longmapsto \left\{ \begin{array}{l} \text{“Yes”} \\ \\ \text{“No”} \end{array} \right. \quad ?$$

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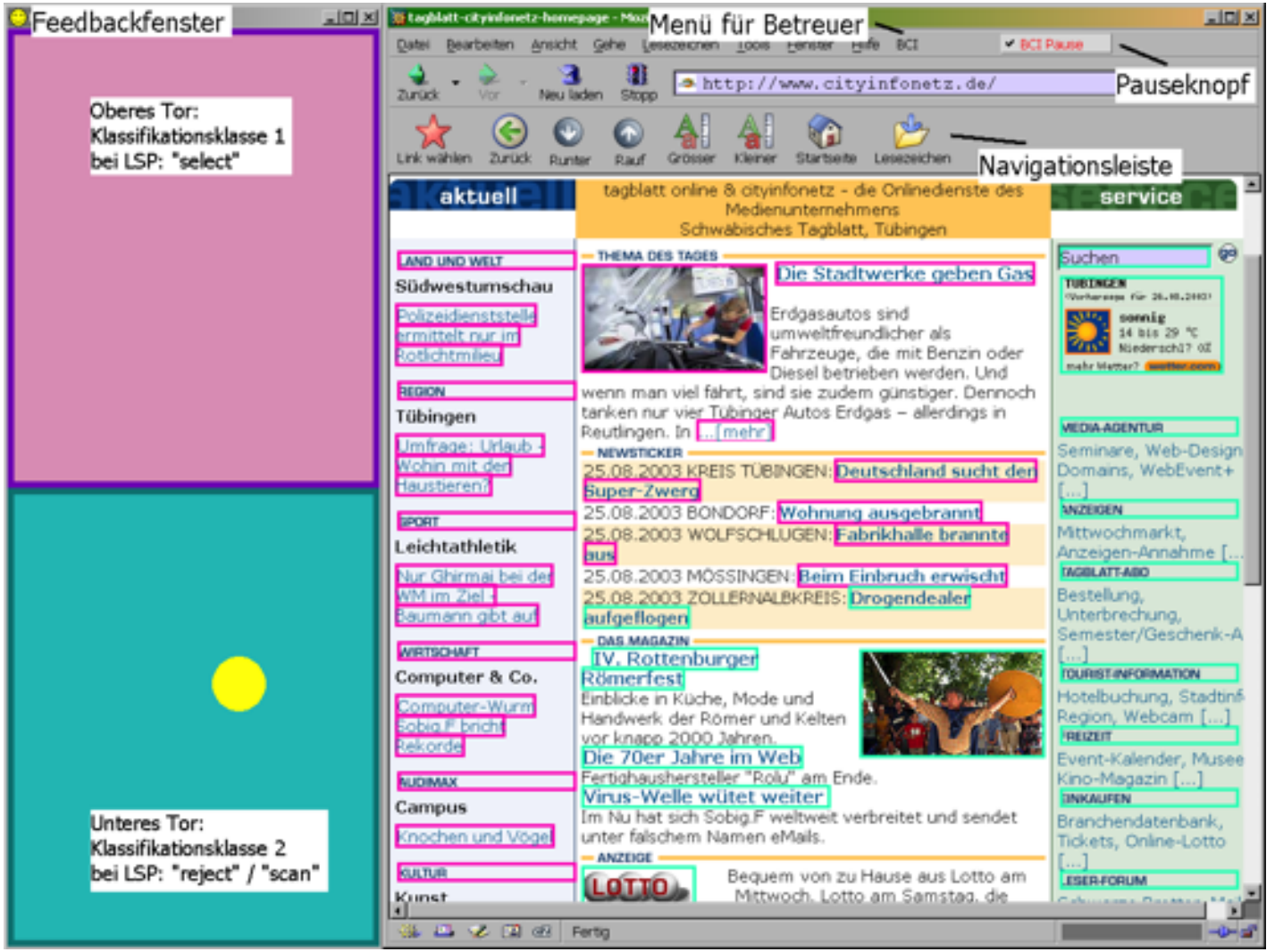


Application: *Nessi* by Michael Bensch

Induction strategies

Imagined-movement: animation by Sandra Cordero and Navin Lal

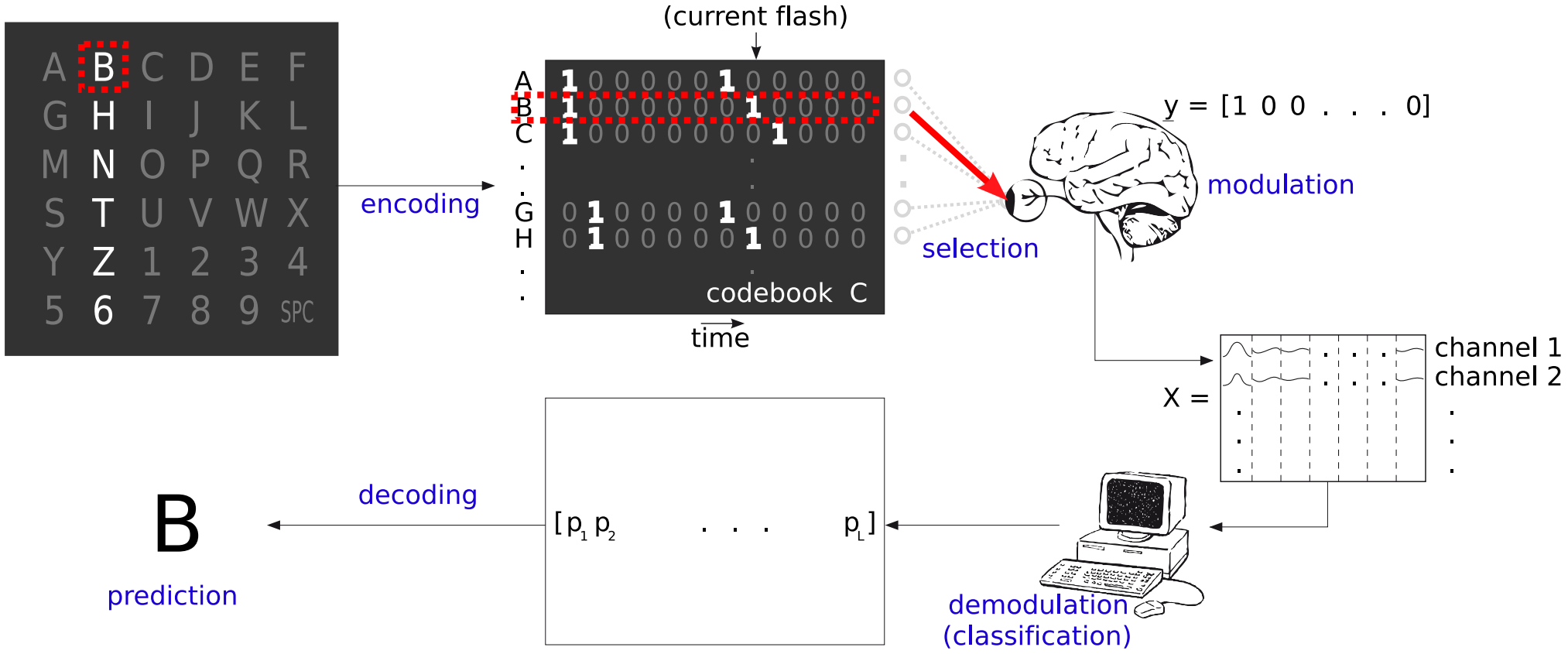
Induction strategies

Imagined-movement: CEBIT demo by Fraunhofer FIRST, Berlin

Induction strategies

Visual grid-speller: video by Inst. Medical Psychology, Tübingen University

Induction strategies



Induction strategies

Imagined movement and the visual grid are the fastest and most promising induction methods so far.

But: for users in CLIS, we may need to invent further methods.

Why Non-Visual?

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- In the CLIS state, patients are functionally blind:

Why Non-Visual?

- In the CLIS state, patients are functionally blind:
  - eyes cannot be opened at will;
  - eyes may move involuntarily (often rolling up);
  - lens cannot be refocused or gaze directed;
  - no microsaccades, so images fade out (Troxler effect);
  - no saccades, so no integration of visual scenes: the fovea images a fixed 2 deg. spot, and resolution is very low in most of the visual field;
  - long immobility of the eye often leads to infections;

Why Non-Motor?

- Motor-imagery-based BCI shows promising results with normal subjects, and patients with extensive paralysis (Kübler et al 2005, Neurology 10). So far it has not worked with patients in CLIS. Why?
  - Can the patient still imagine movement?

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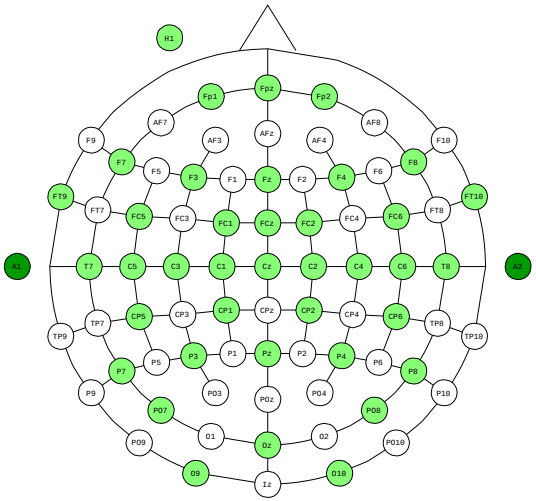
  - (...and are these in fact the same question?)
  - Are ALS patients' motor cortices still intact enough to (relearn to) do so?
    - ⋆ EEG is still the most attractive technology for clinical BCI.
    - ⋆ Most of the EEG signal comes from pyramidal neurons.
    - ⋆ ALS kills the pyramidal neurons of the motor cortex.

Auditory stimulation in EEG



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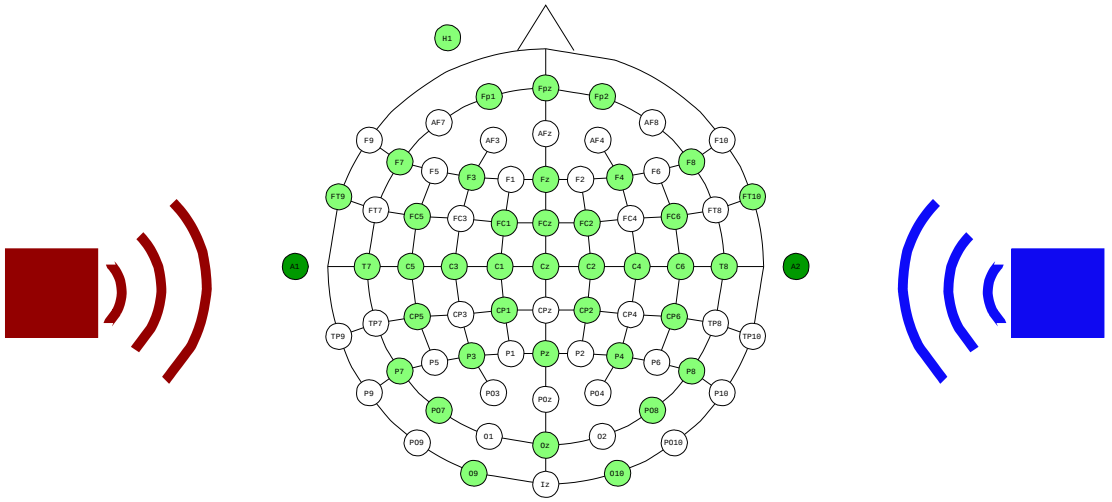

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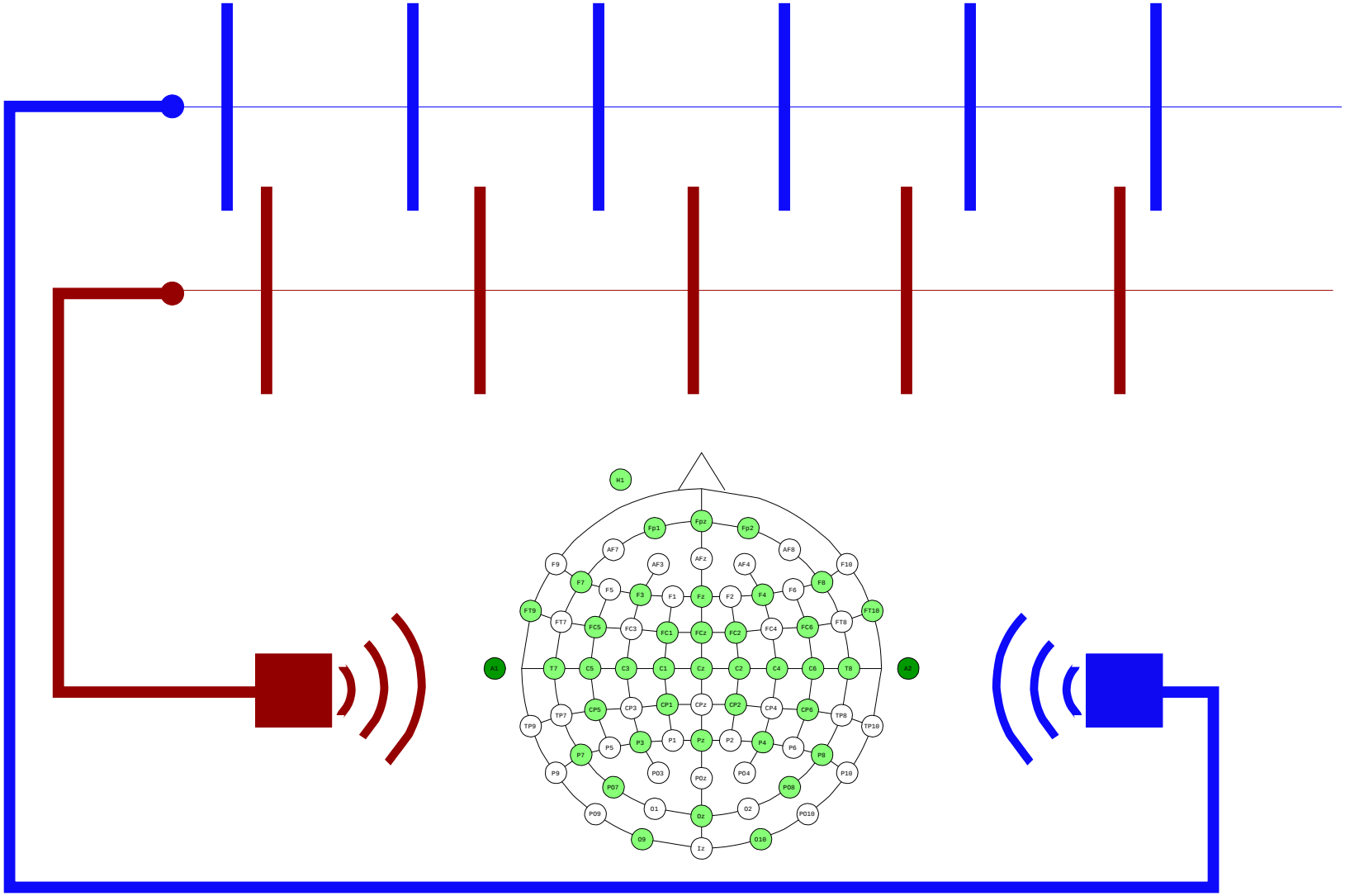

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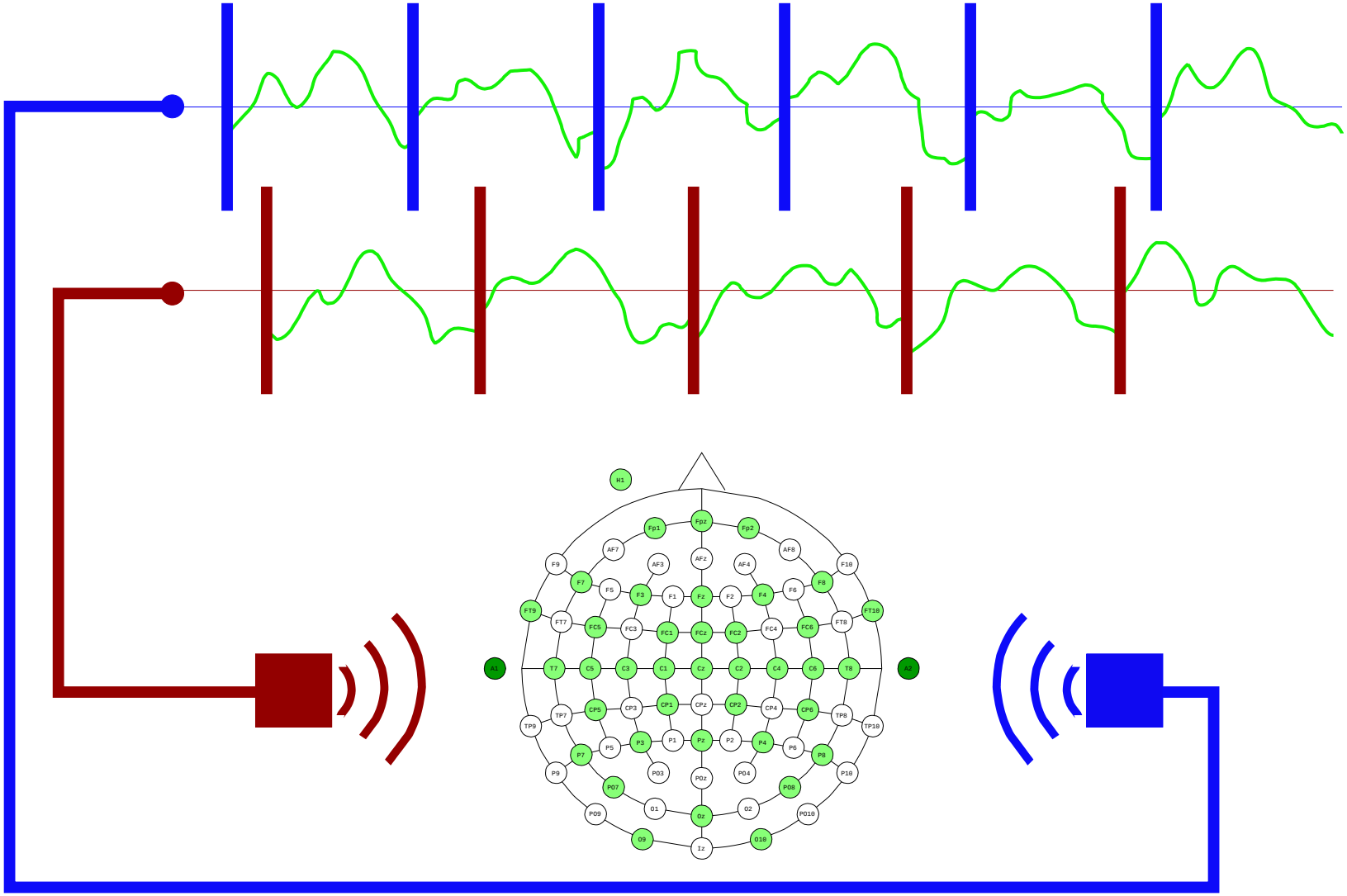

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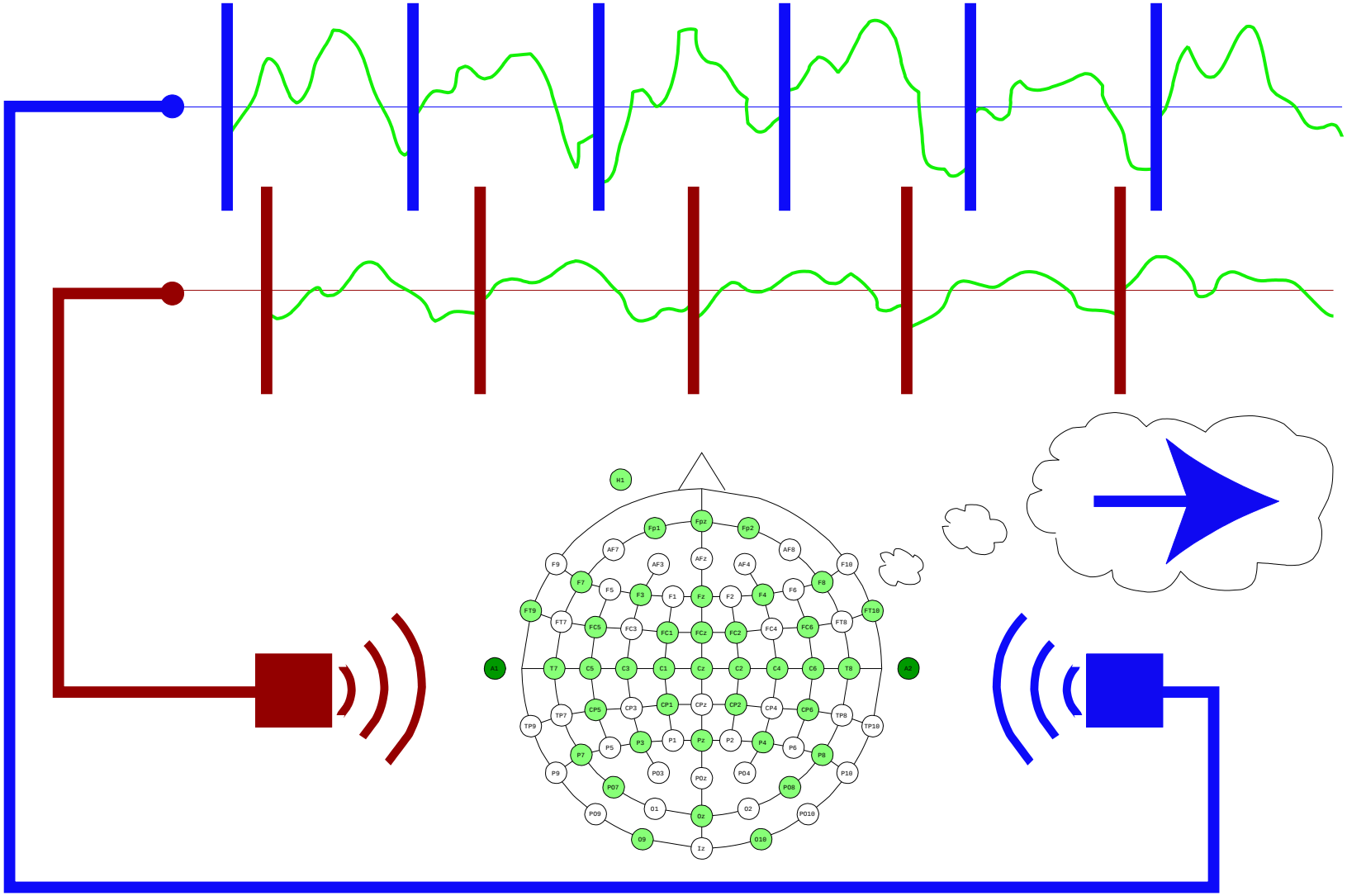

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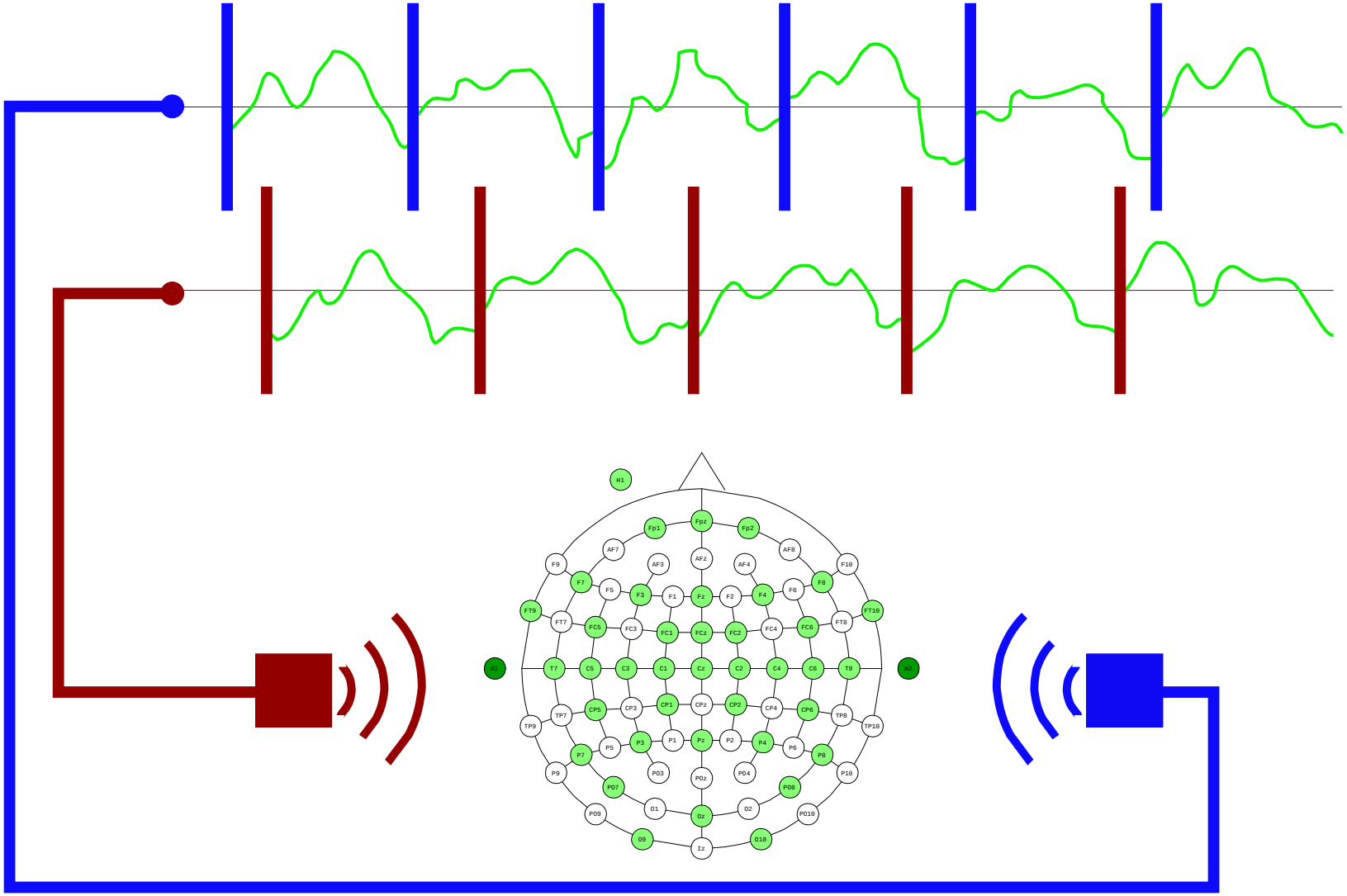

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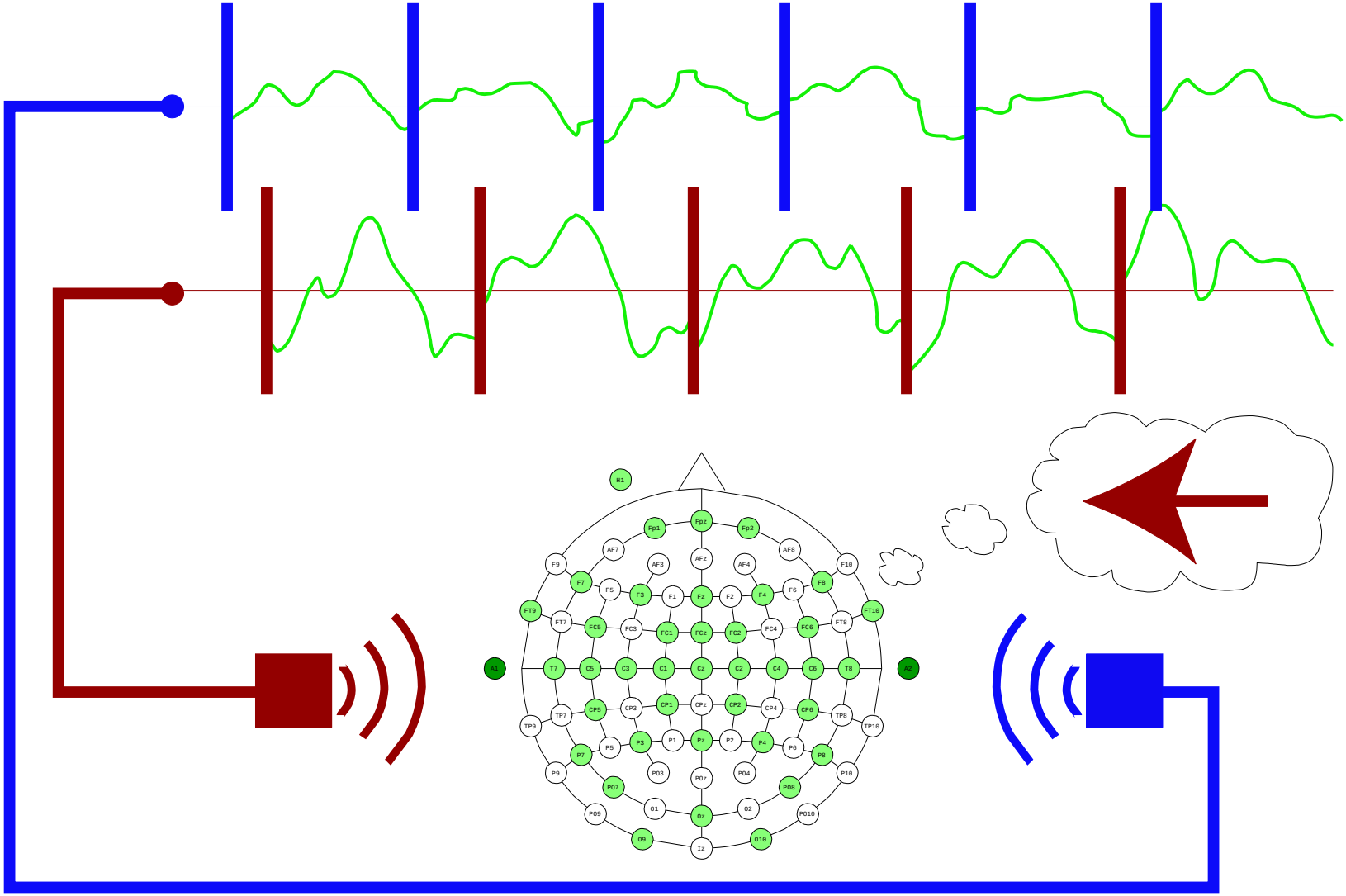
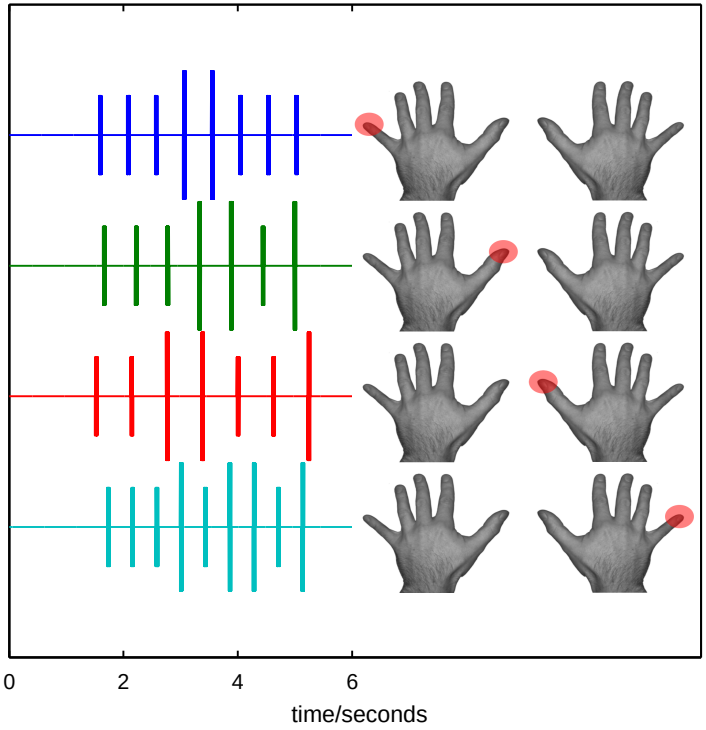
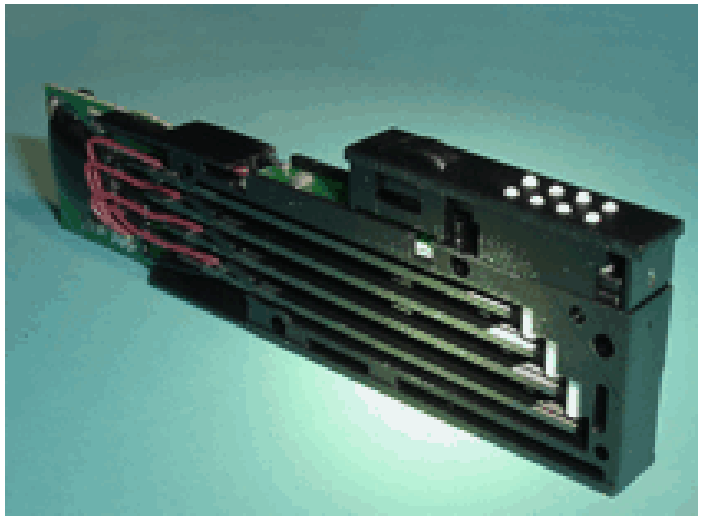


Tactile stimulation in MEG





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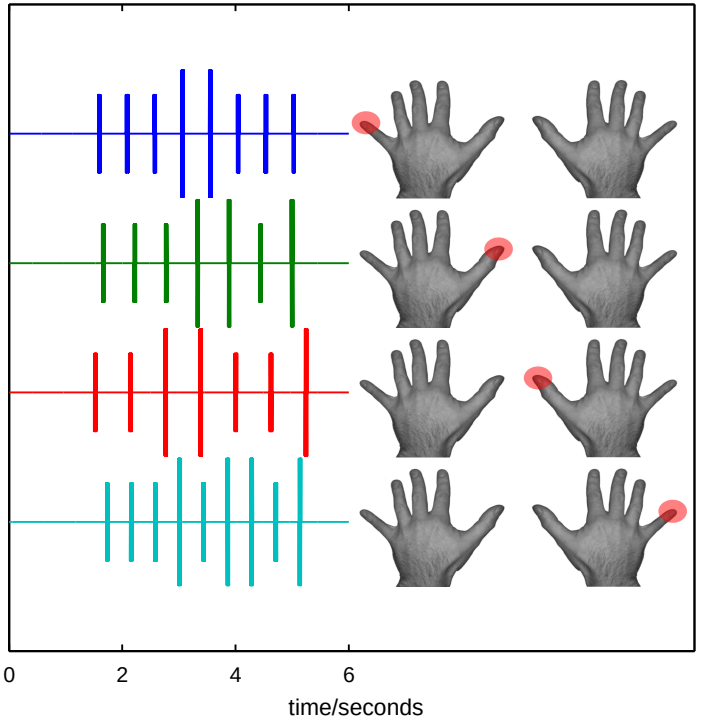
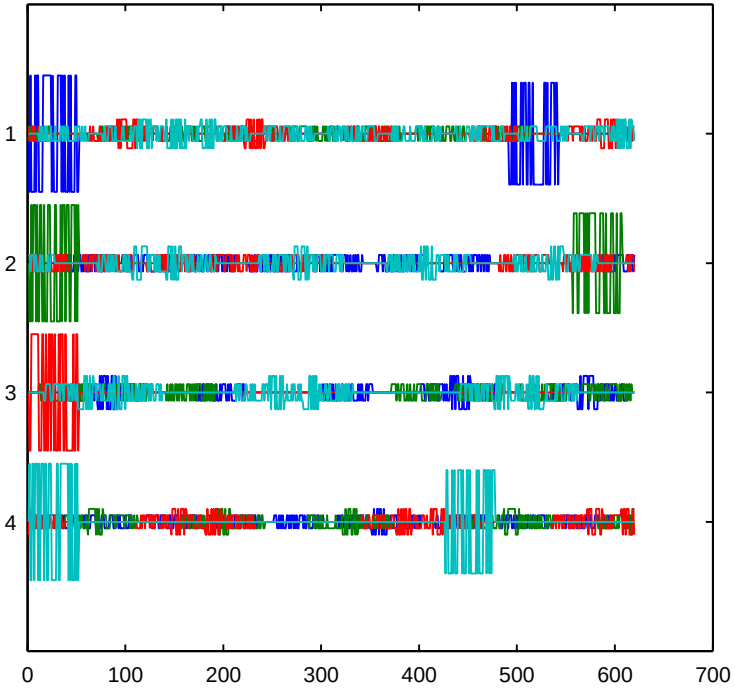
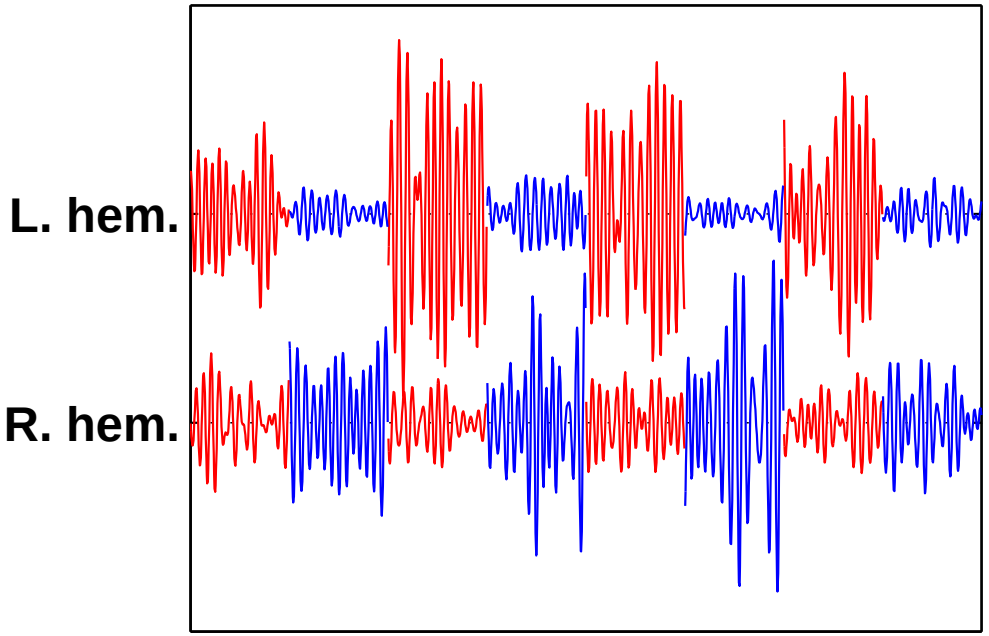
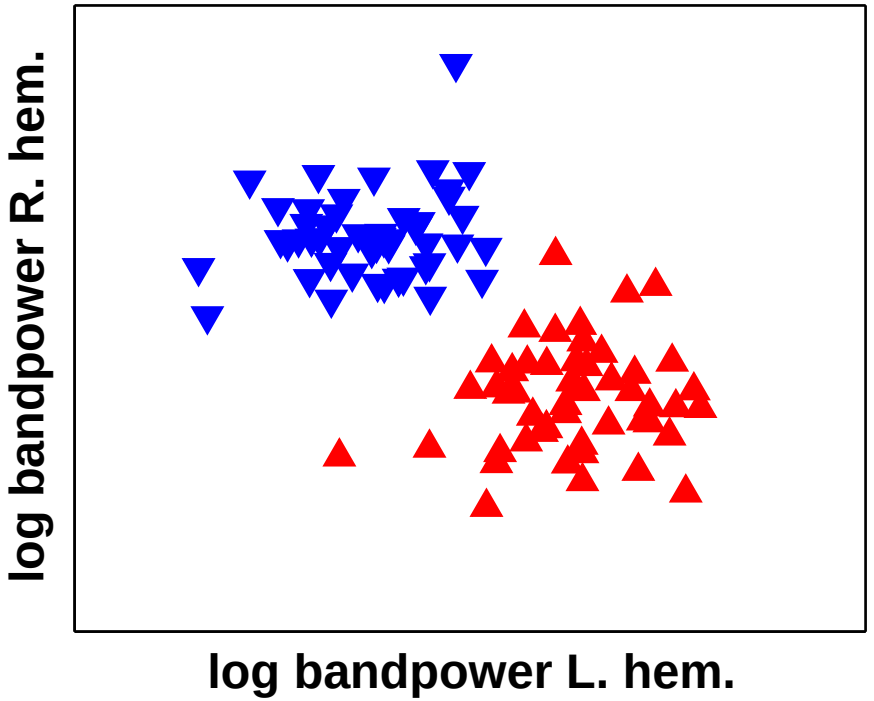




Decoding

Event-Related Desynchronization in motor imagery: classify imagined left hand movement vs. imagined right hand movement based on power in 10 Hz-band of estimated pre-motor cortex sources in the left and right hemispheres.





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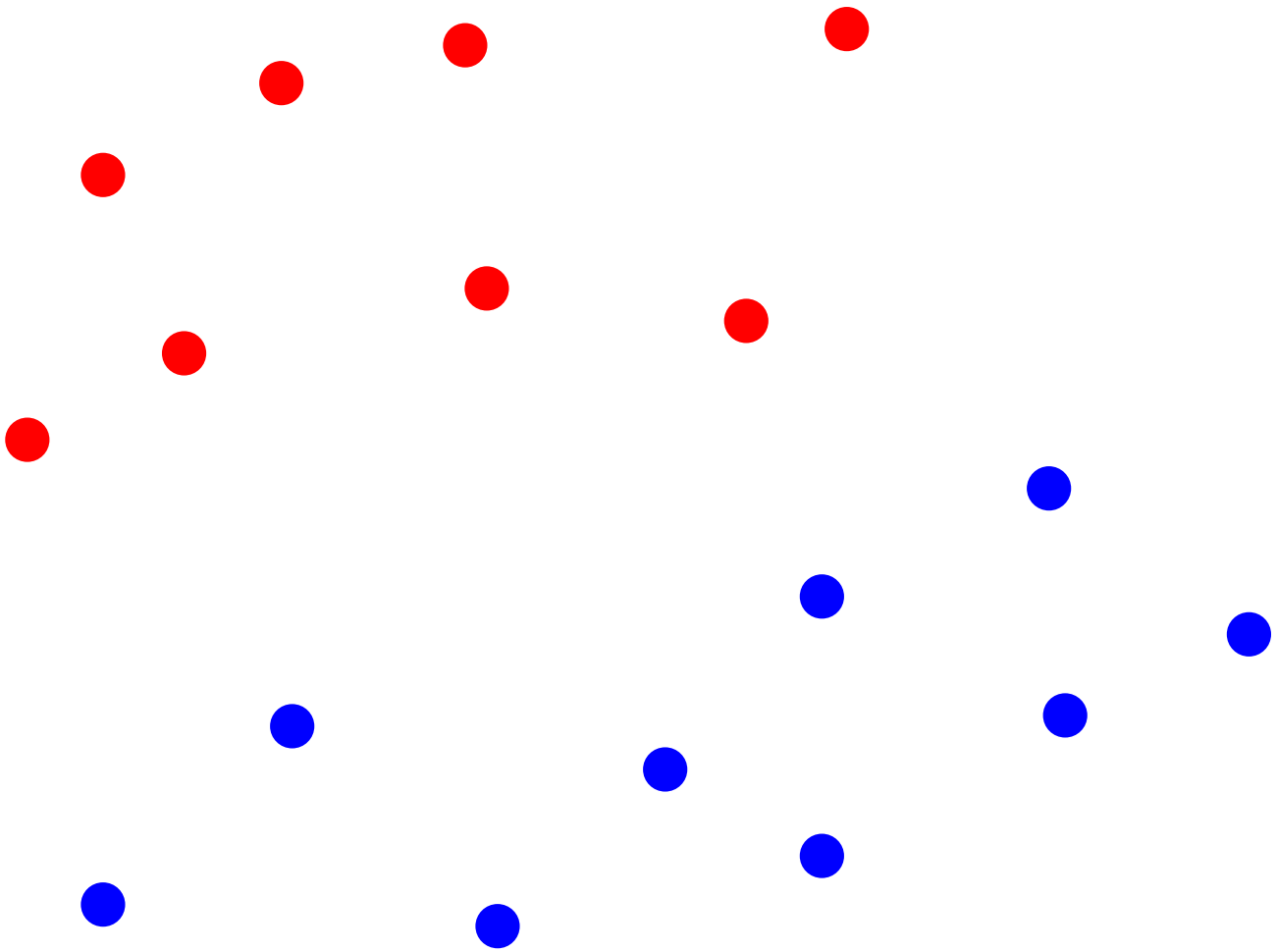

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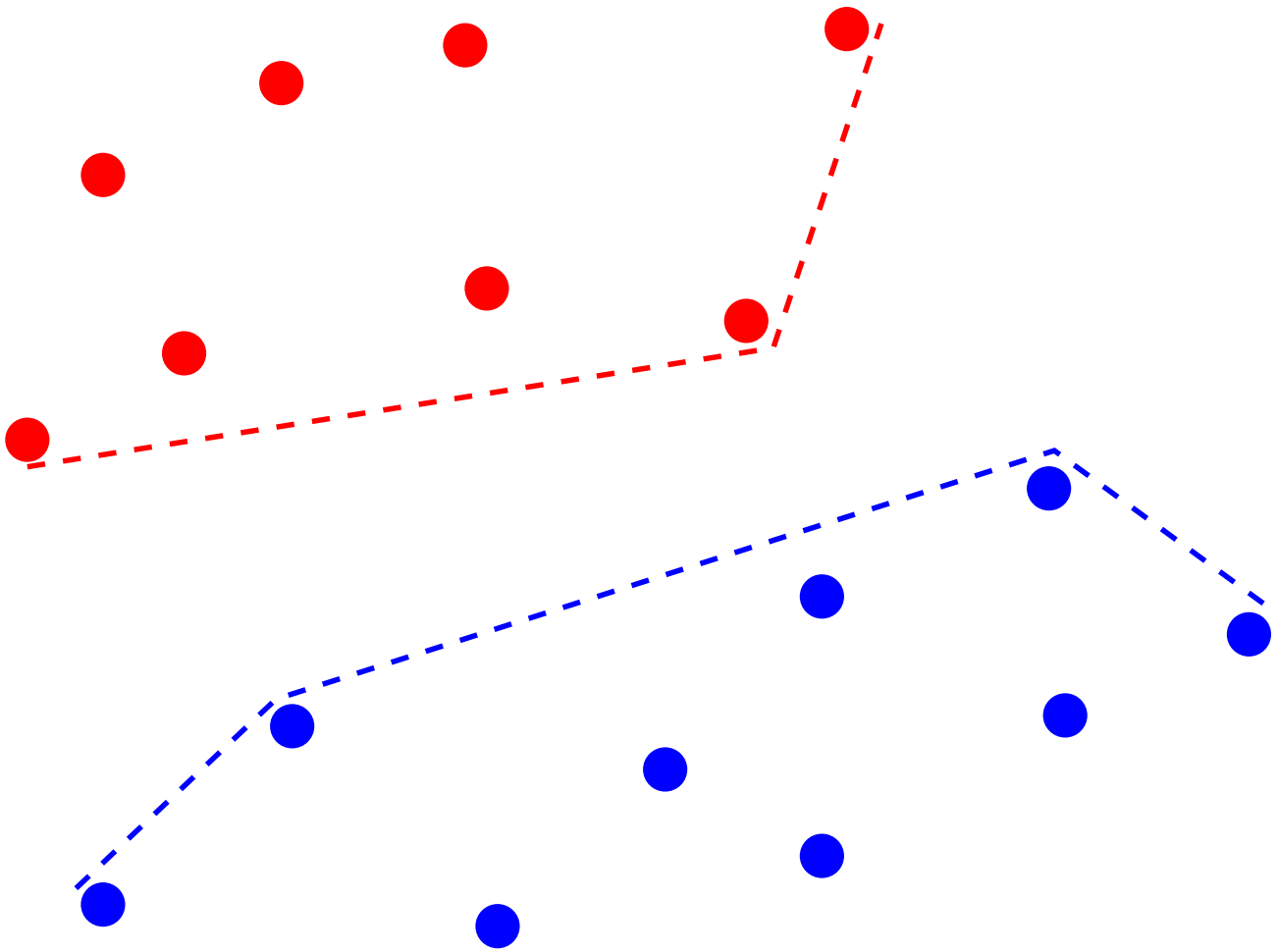

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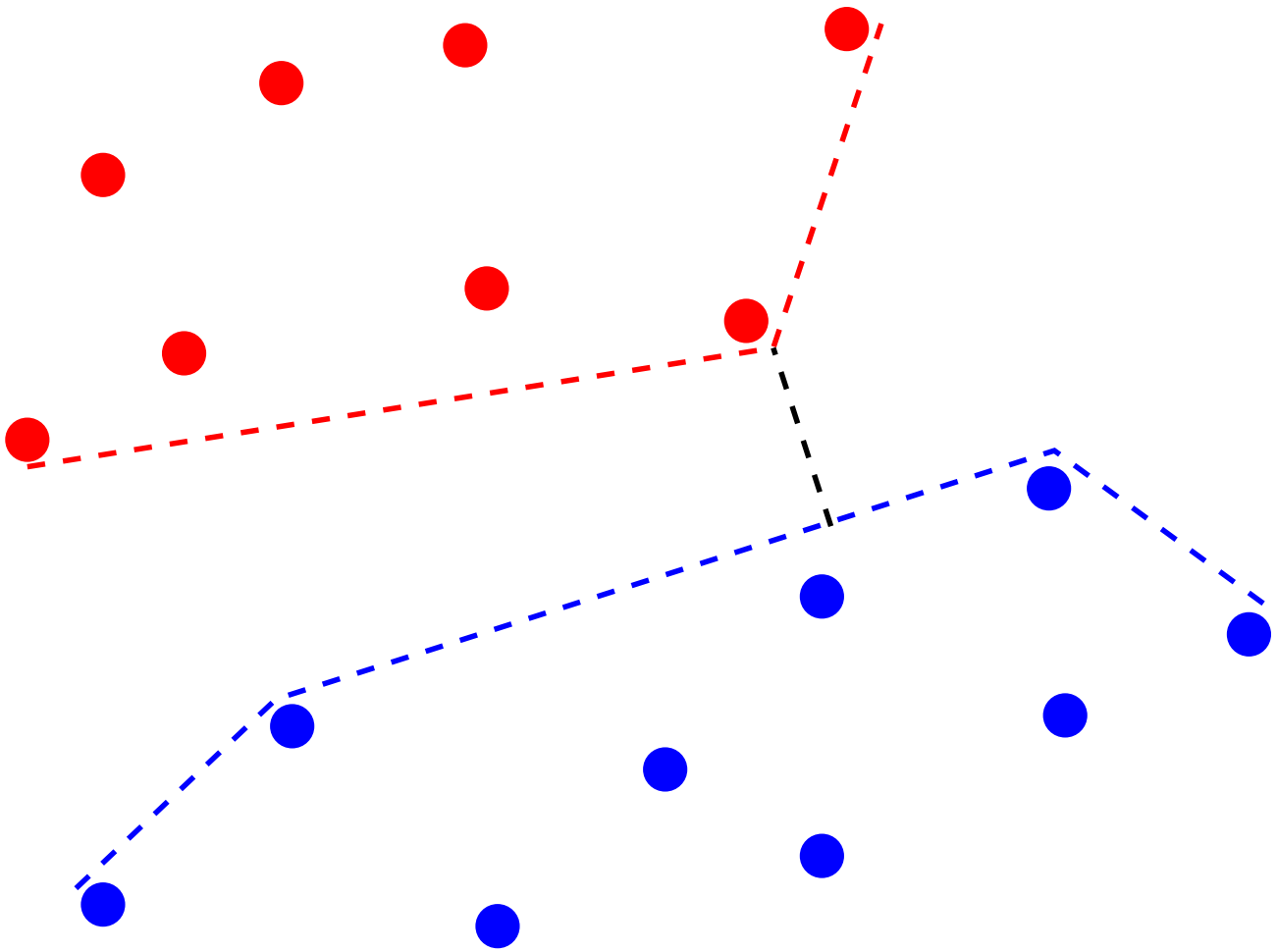

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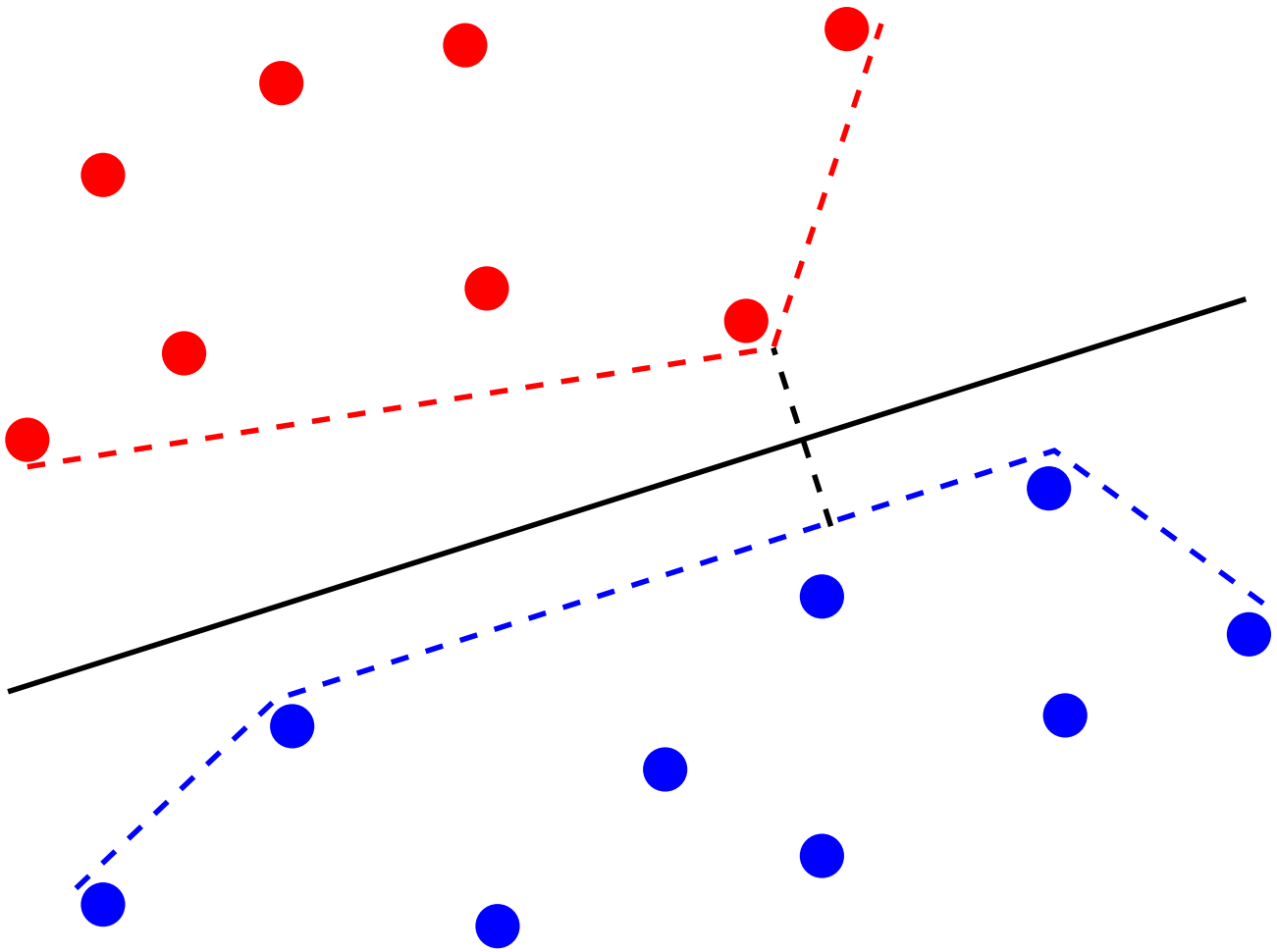

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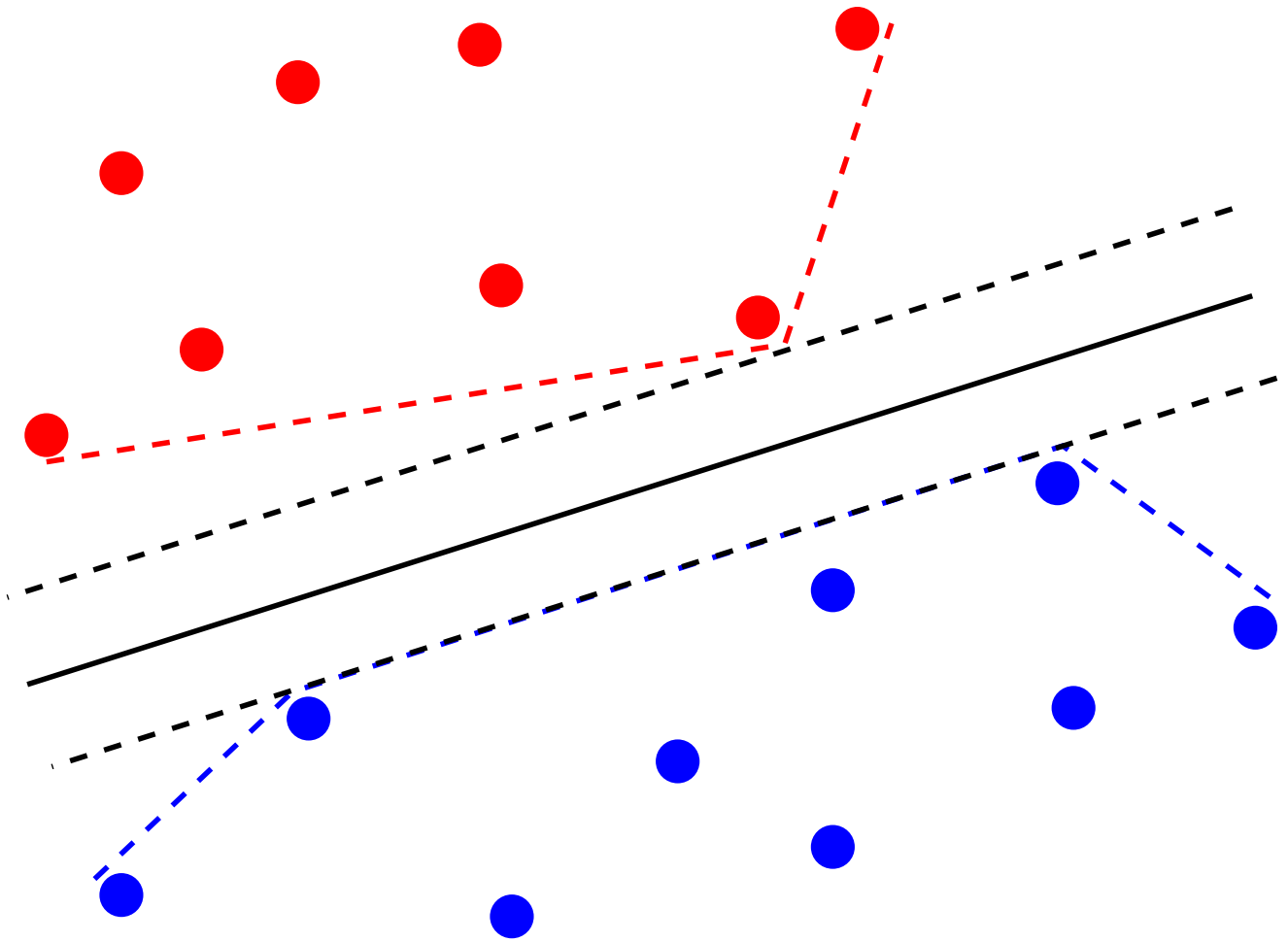

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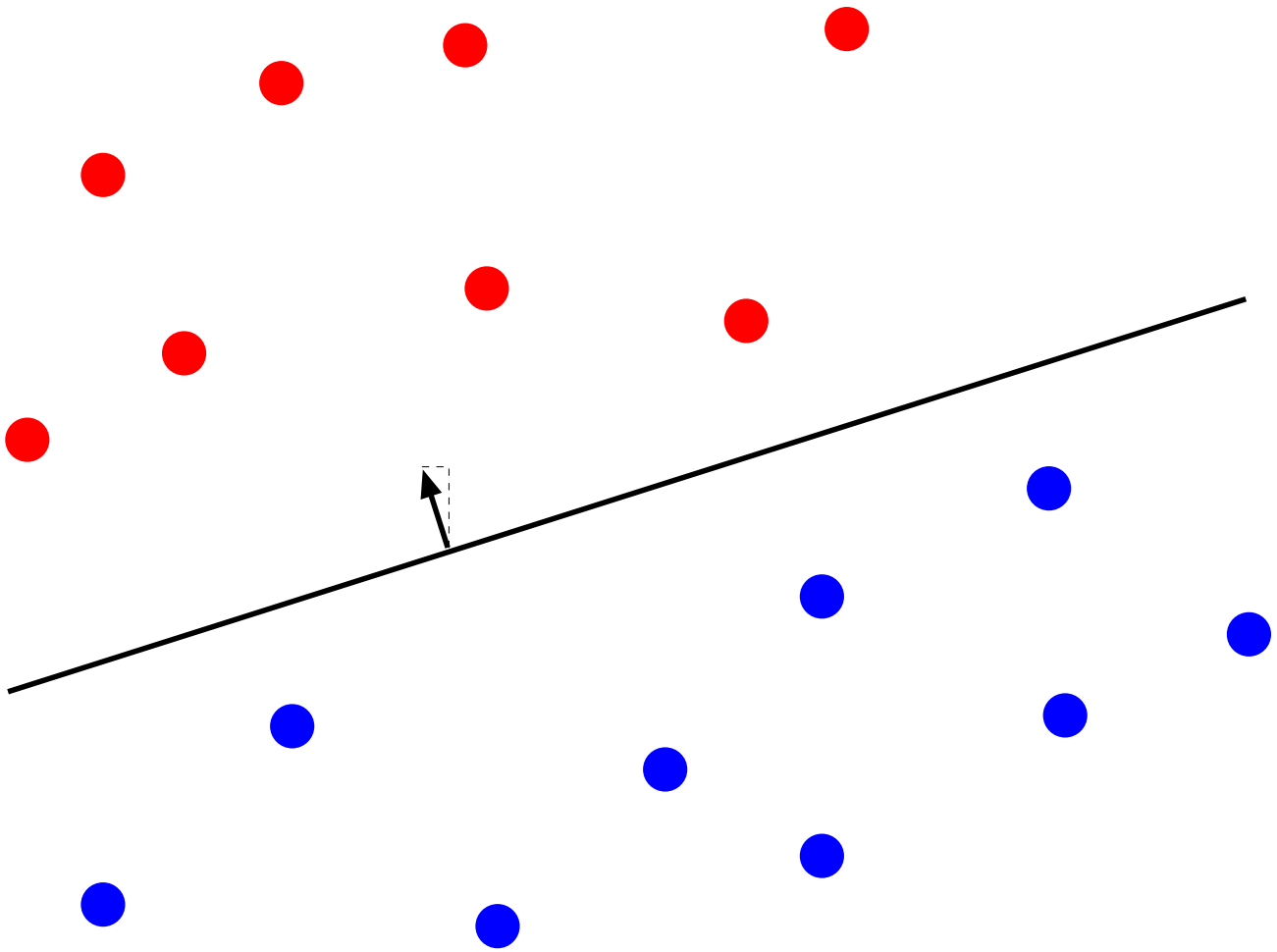

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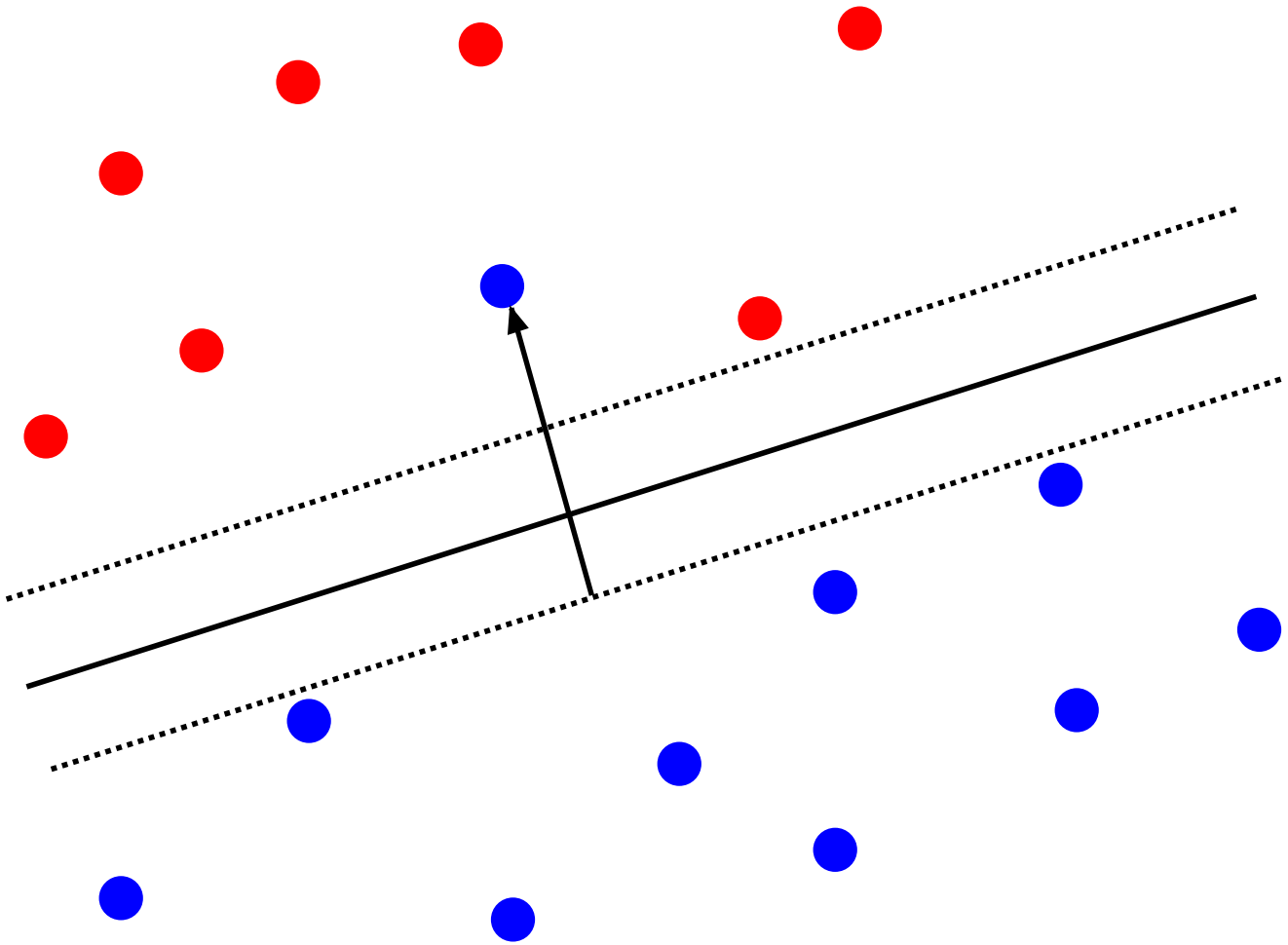

One extra parameter to find (regularization parameter C): how much to penalize cases like this.

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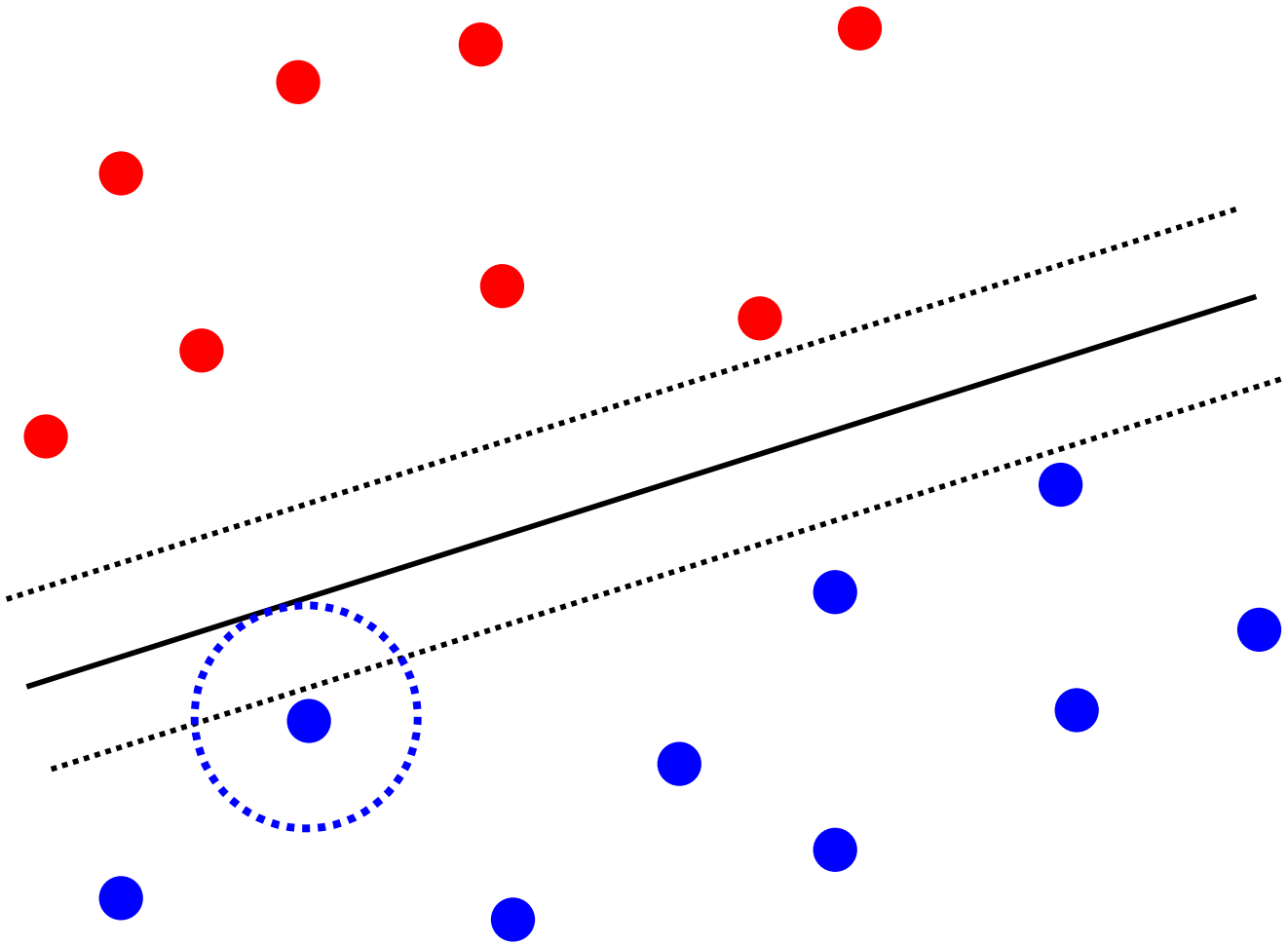

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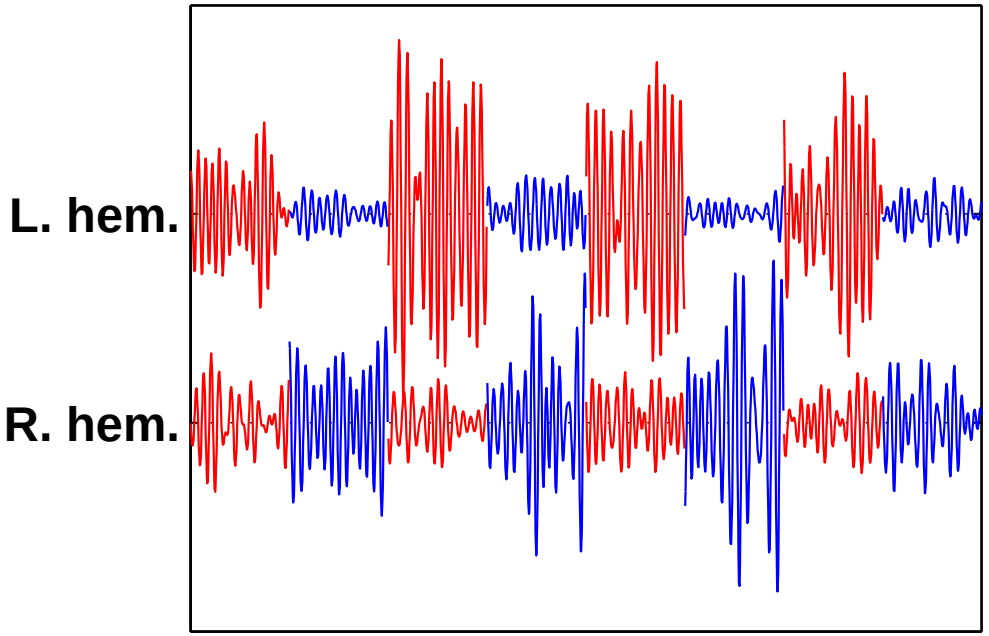
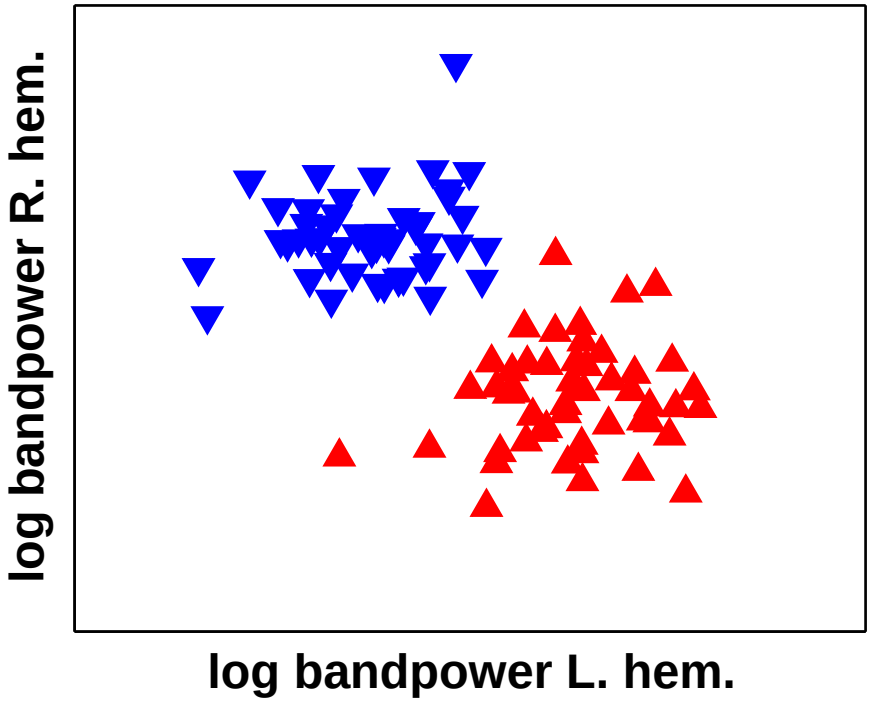
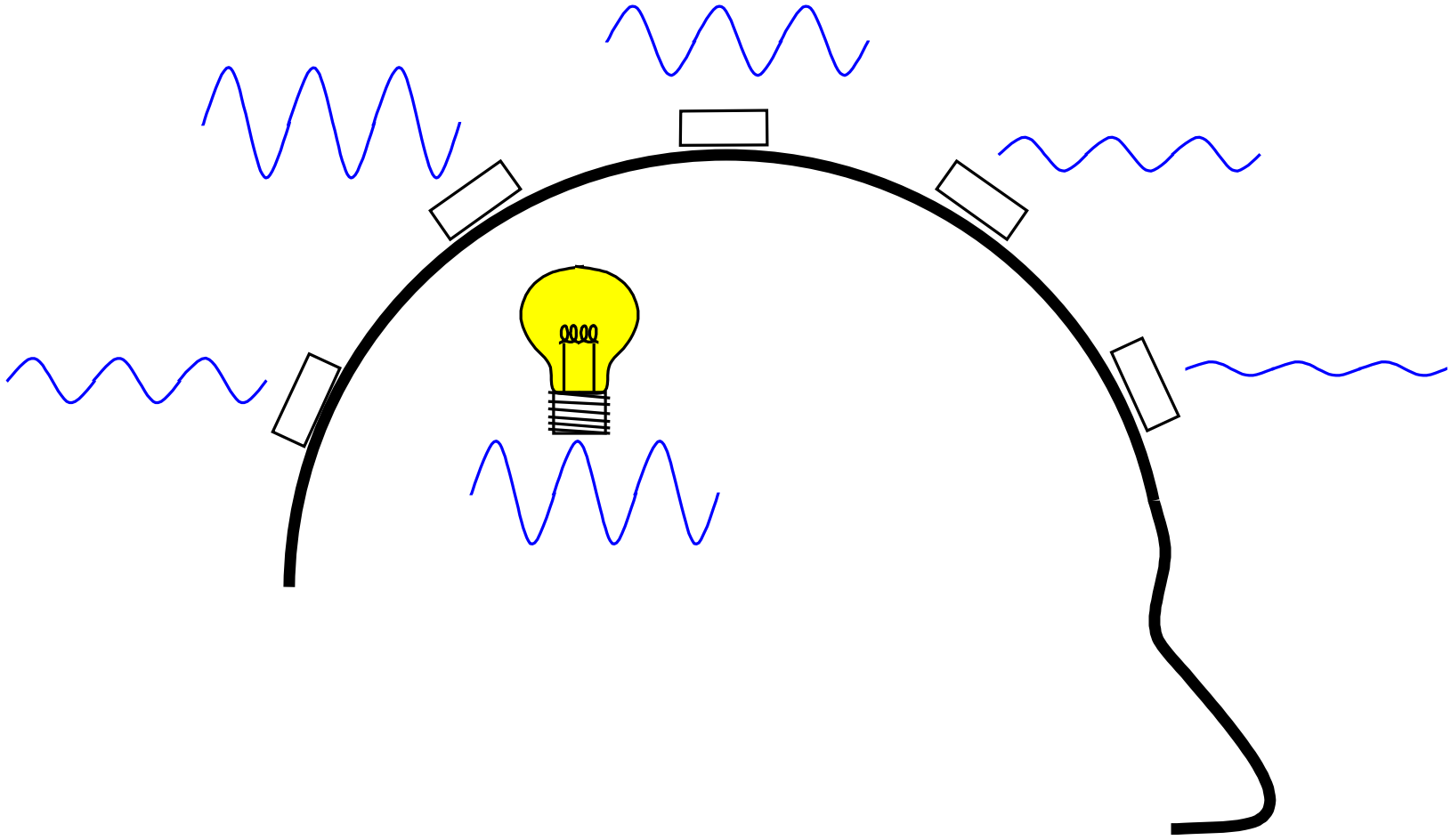
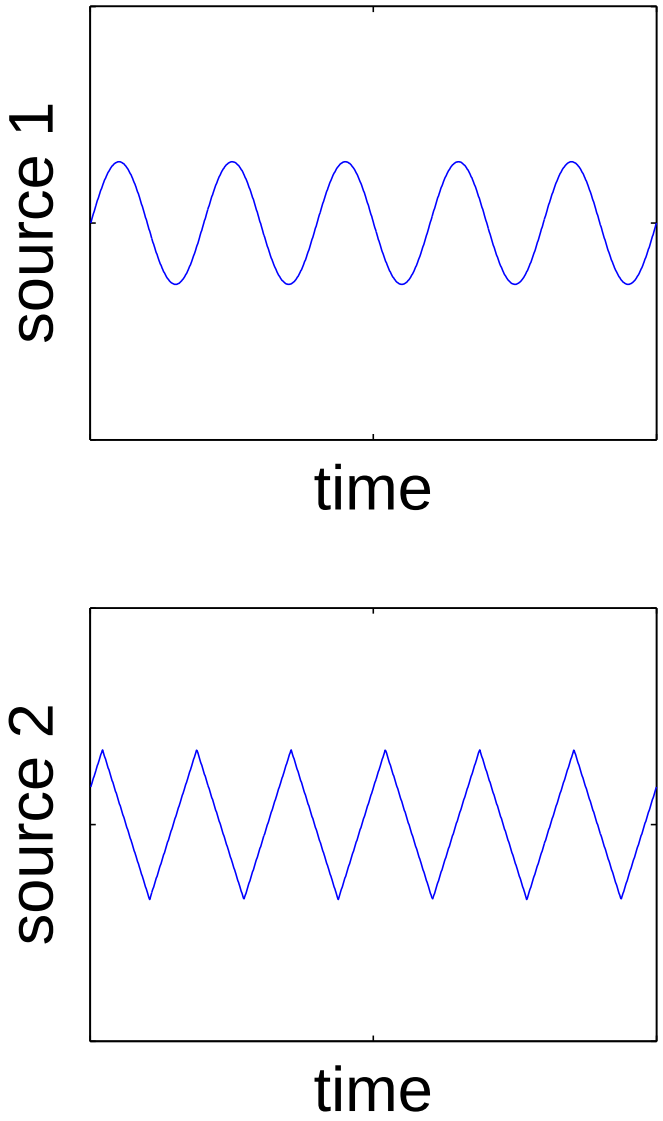


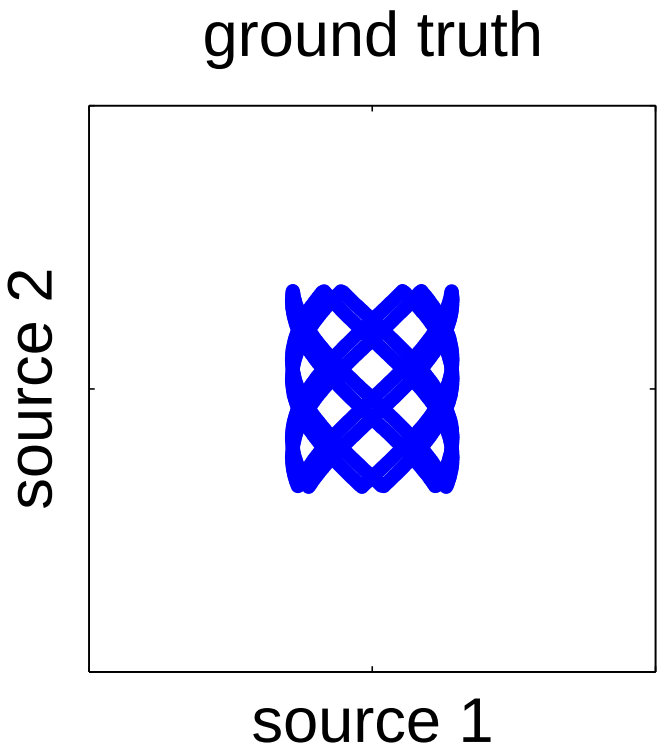


The Volume Conduction Problem



Blind Source Separation





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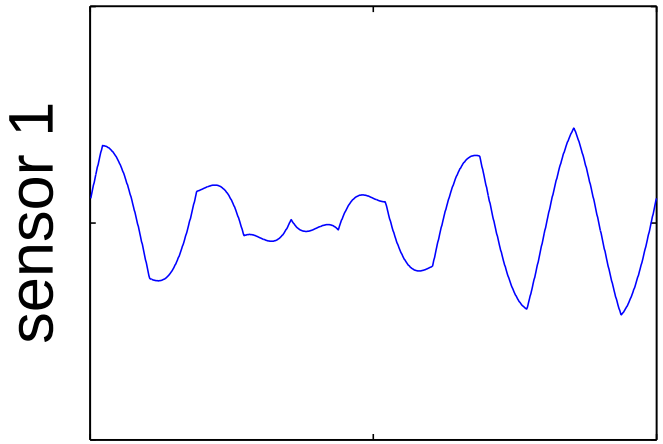

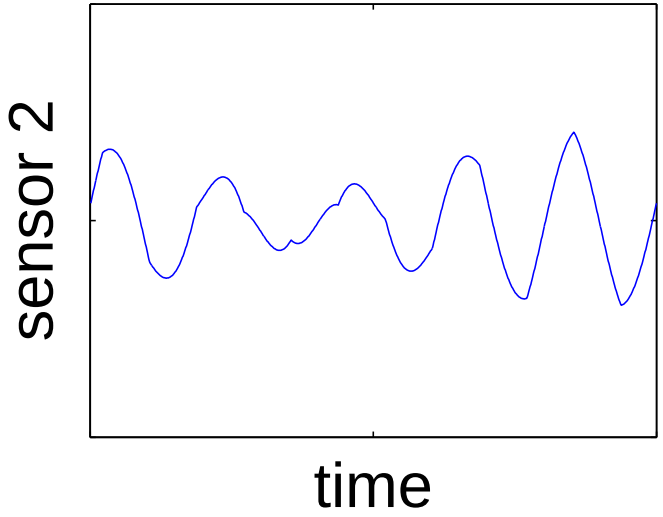

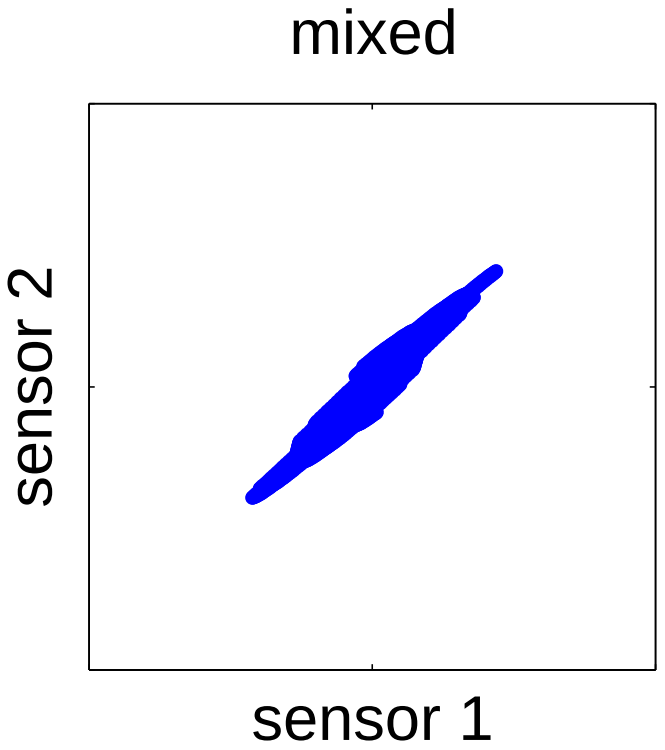

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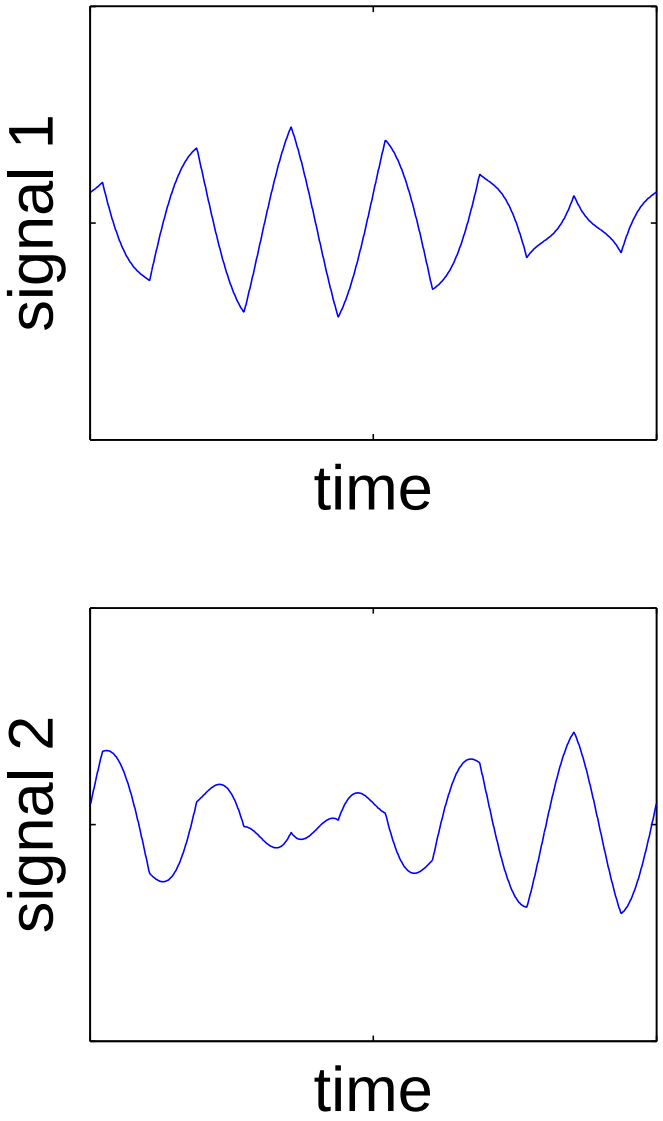

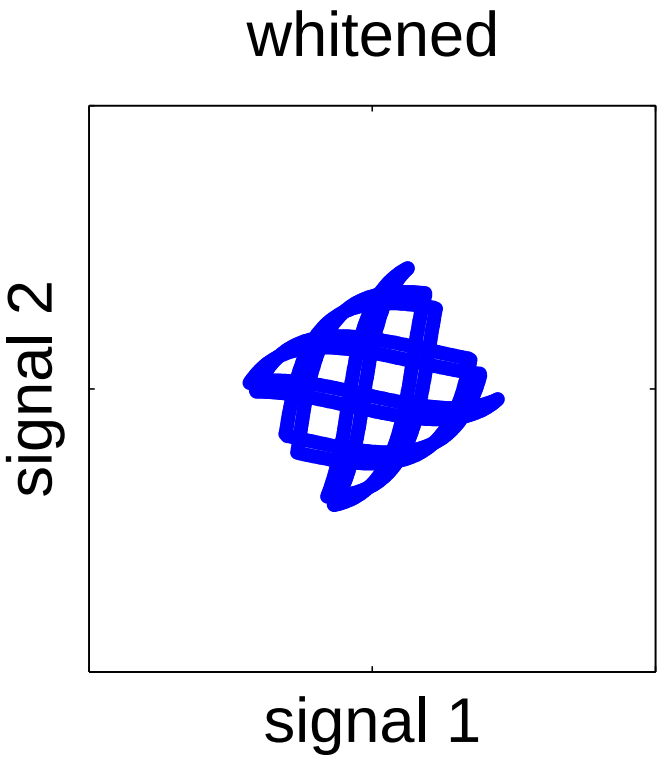

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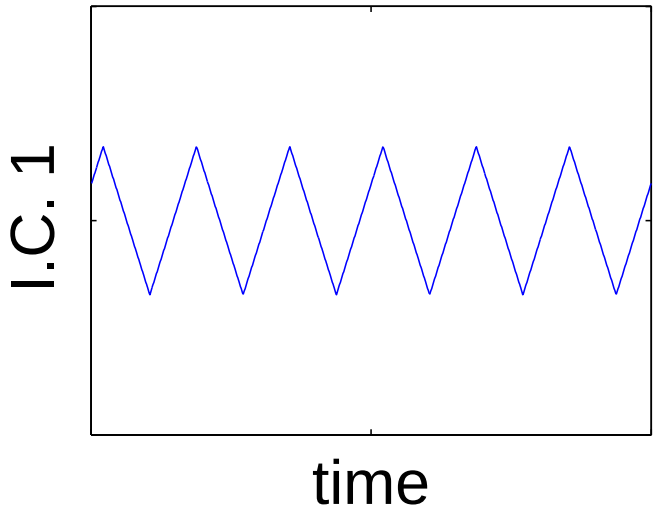
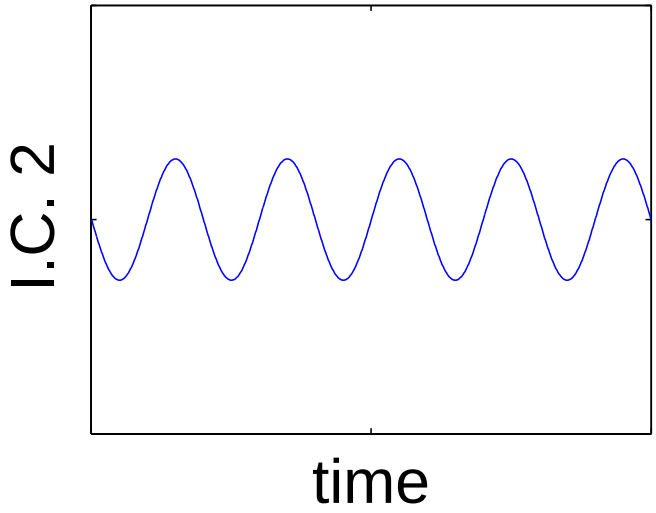
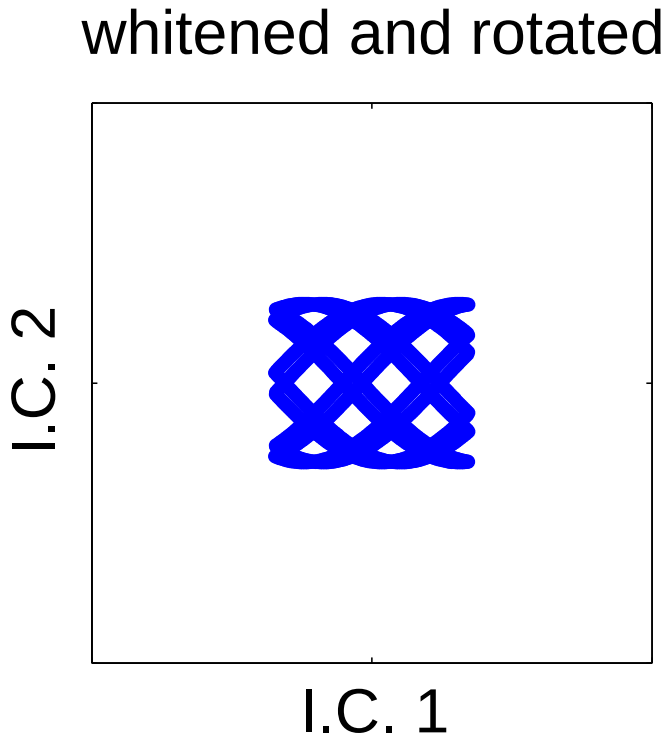
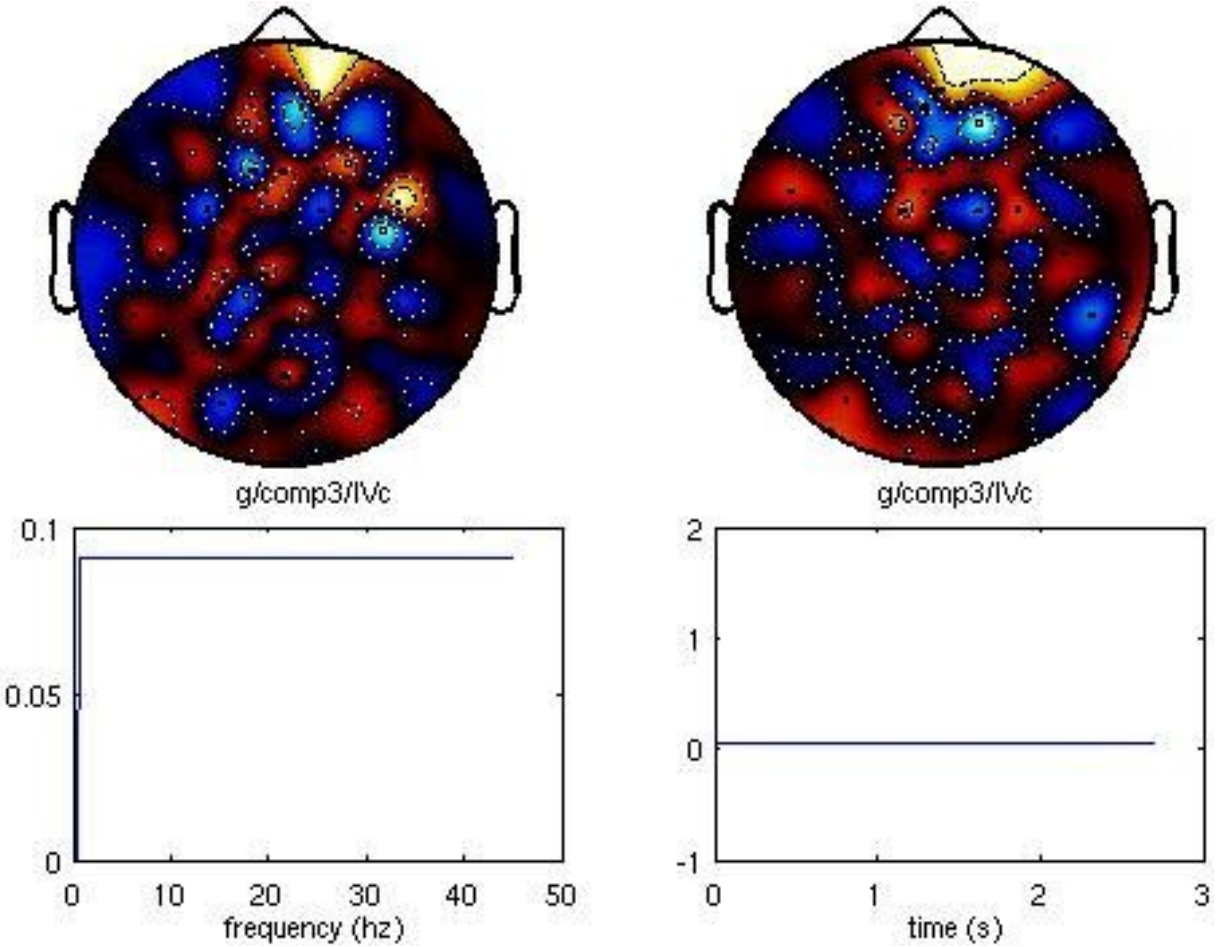






Spatial, temporal, spectral...

Jason Farquhar (MPI Tübingen) has developed a single optimization method which combines the principles of *maximum-margin classification* and *blind source separation*. It can automatically tune in to the right frequency, time window and spatial filter:



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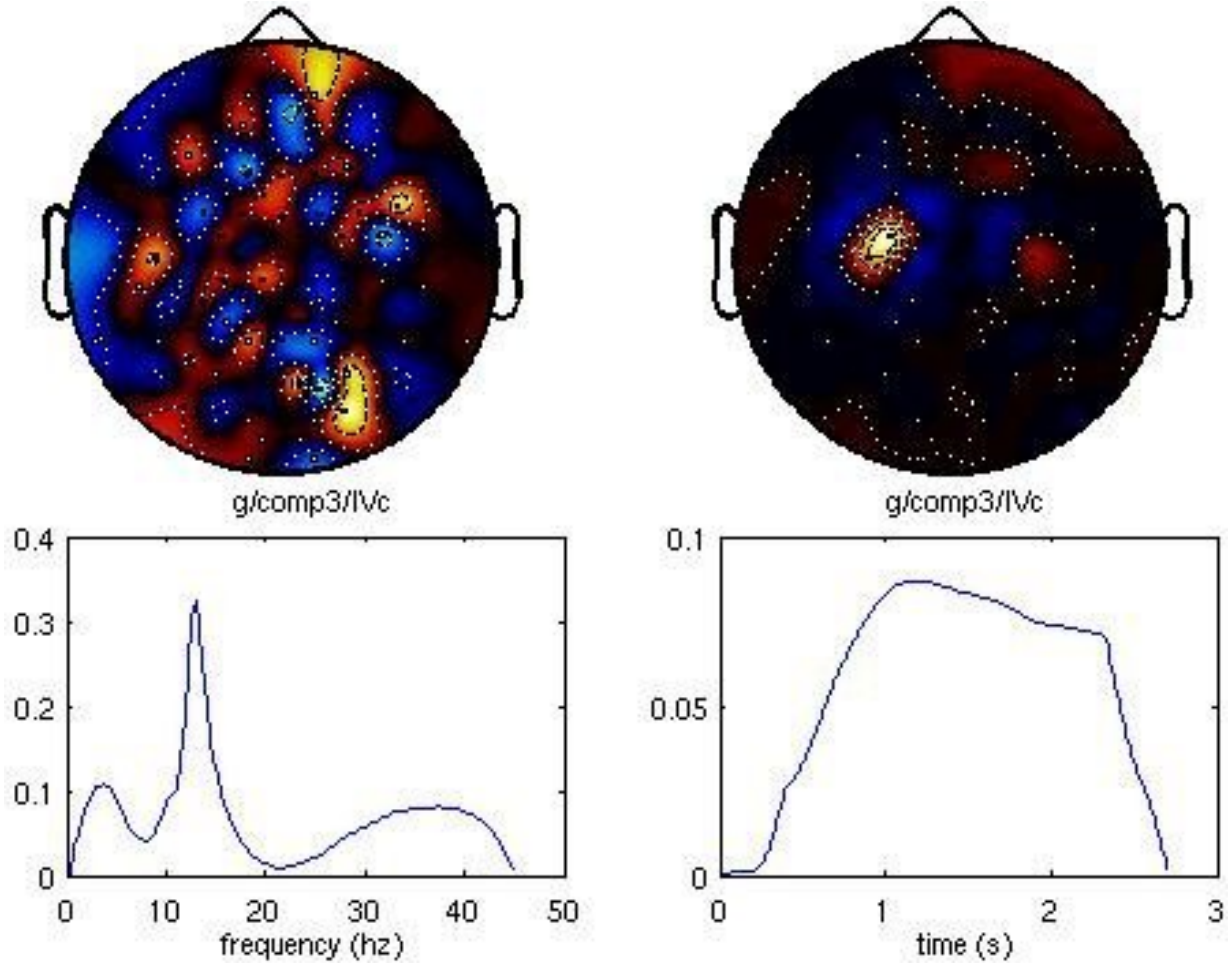

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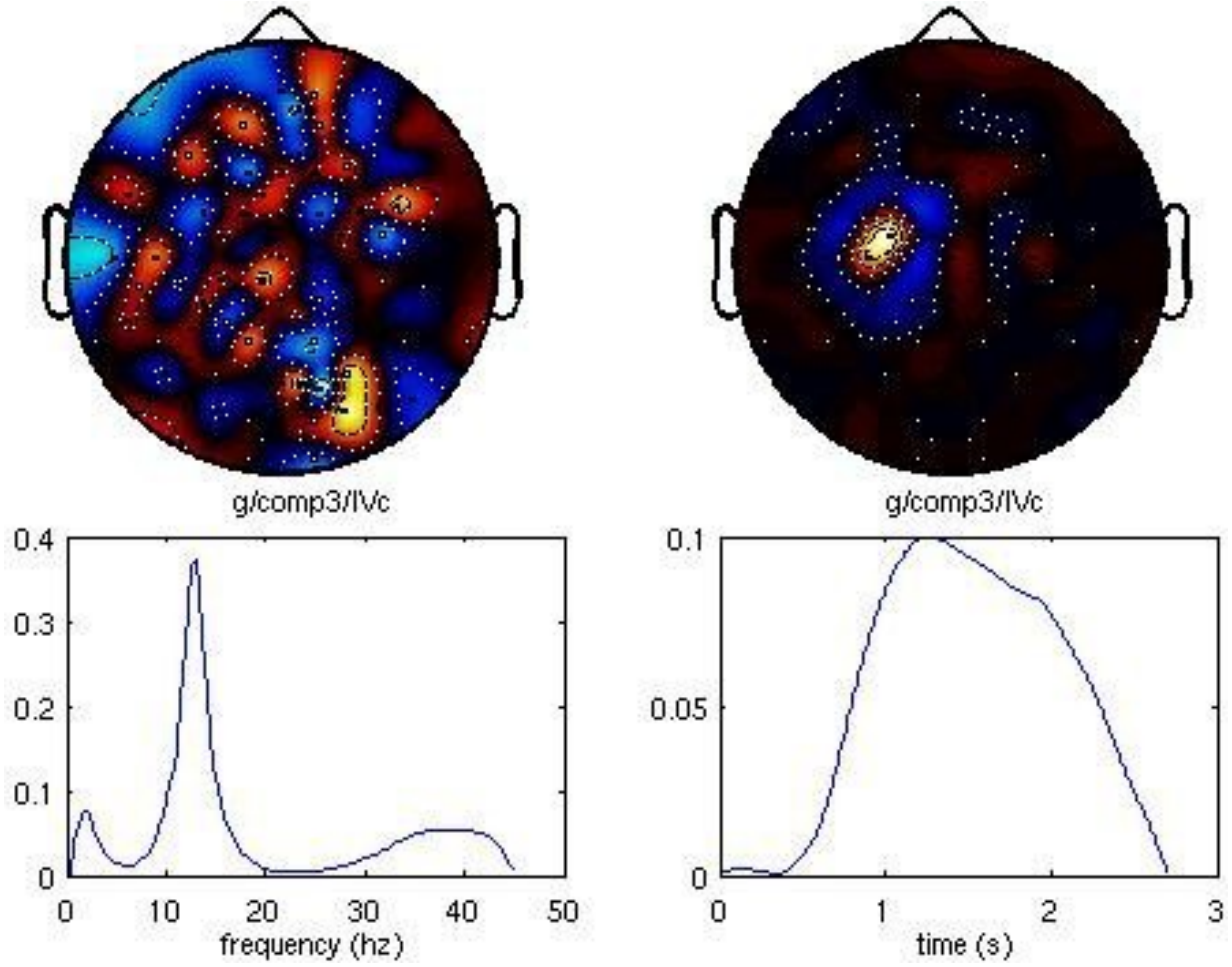

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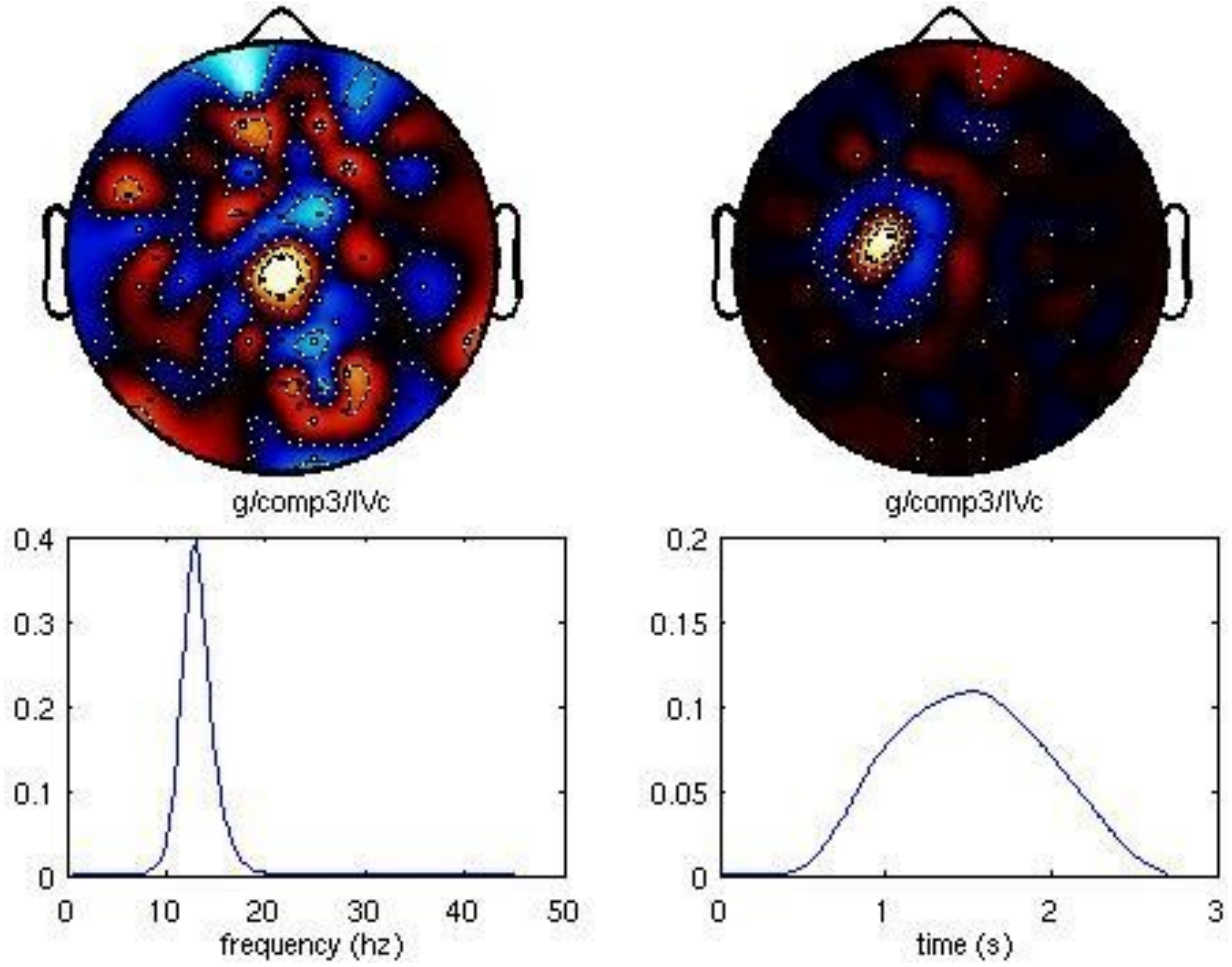

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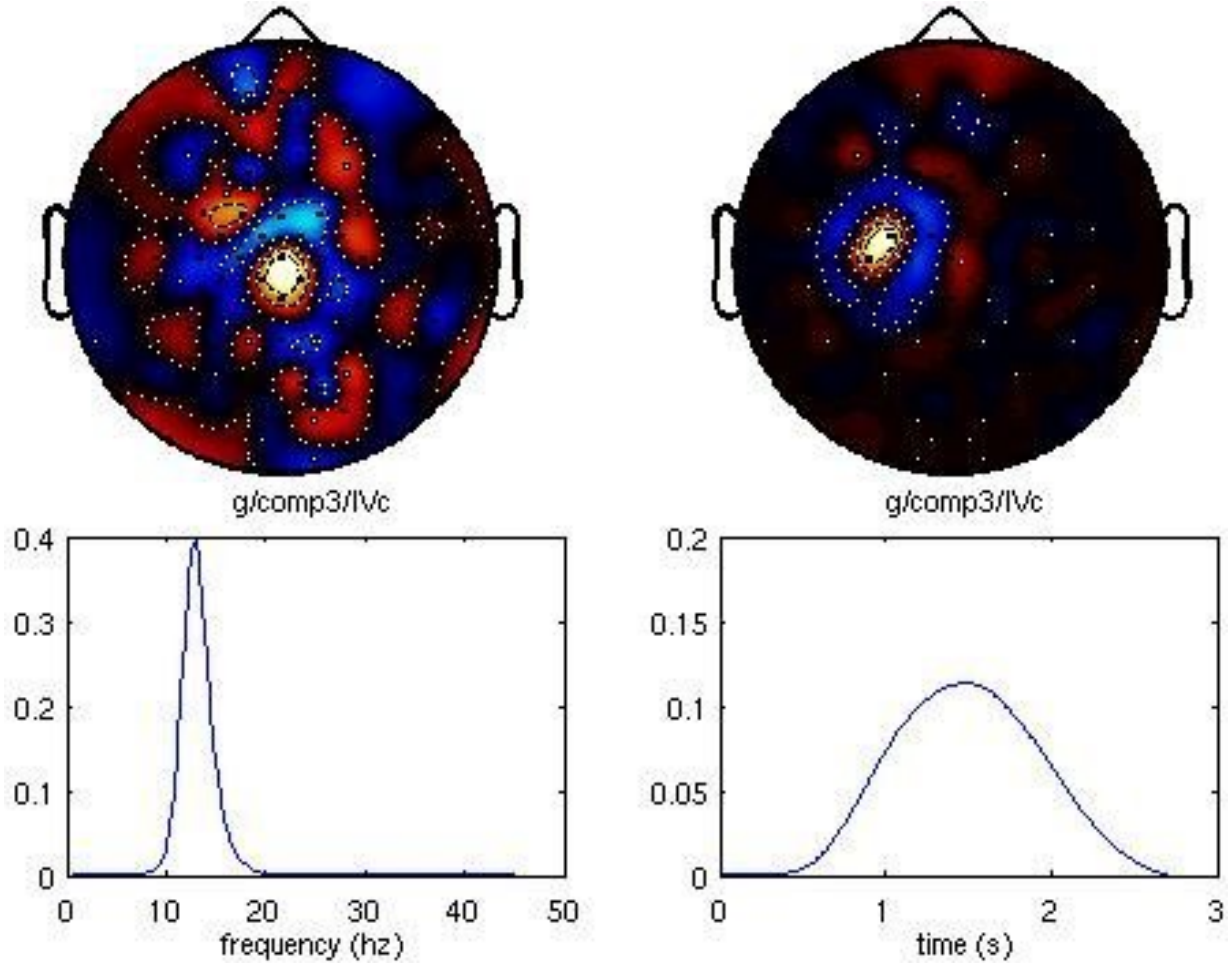

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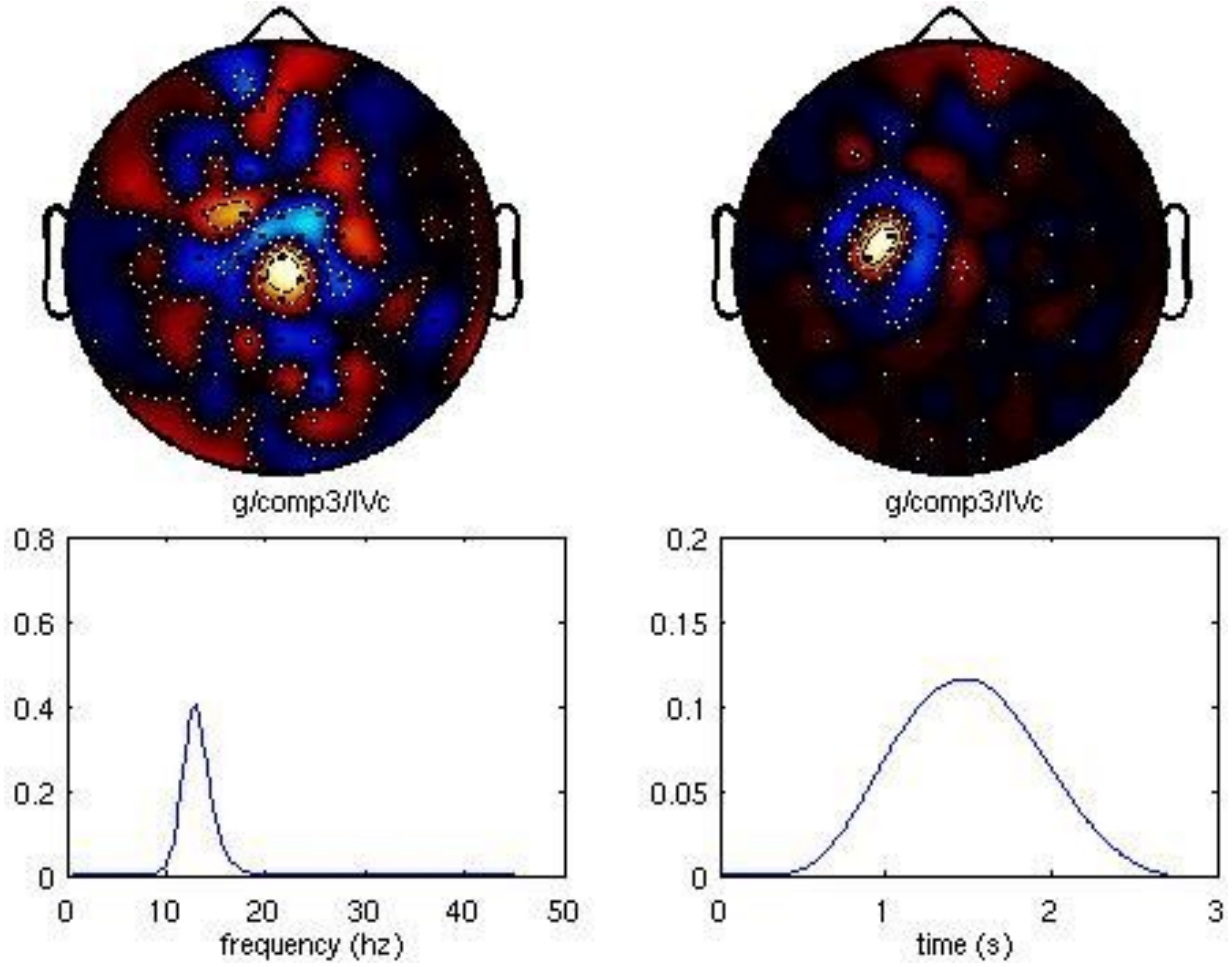

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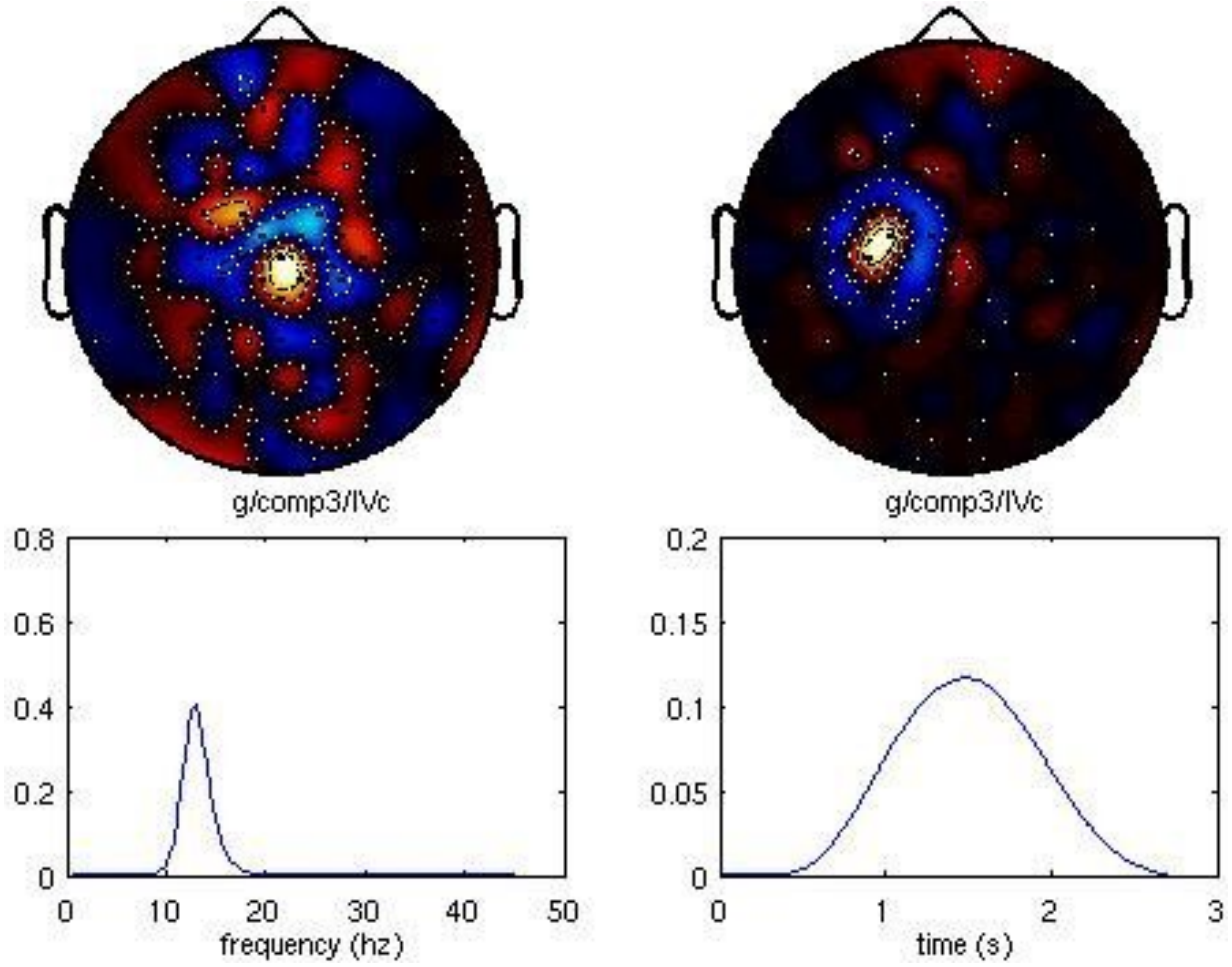

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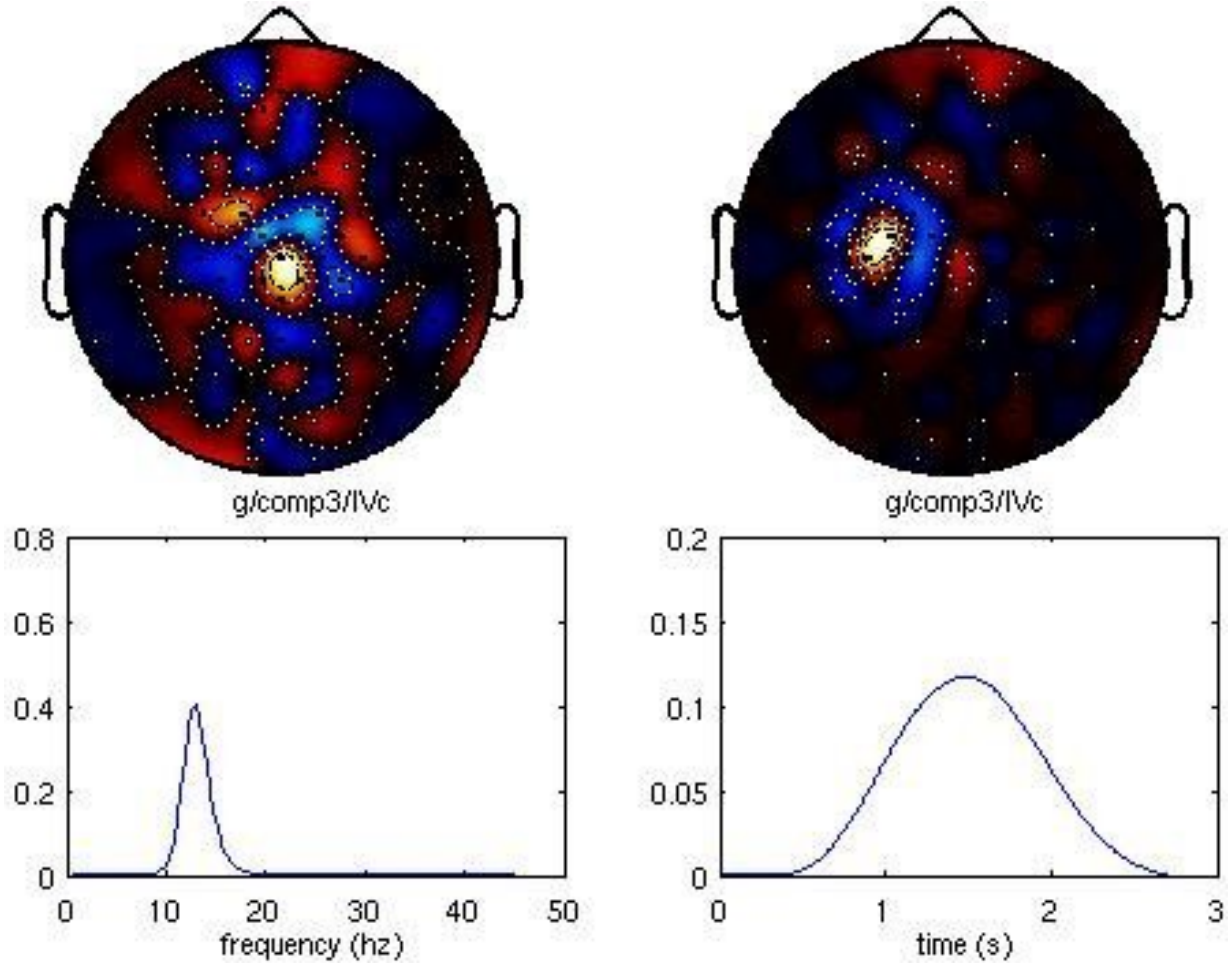
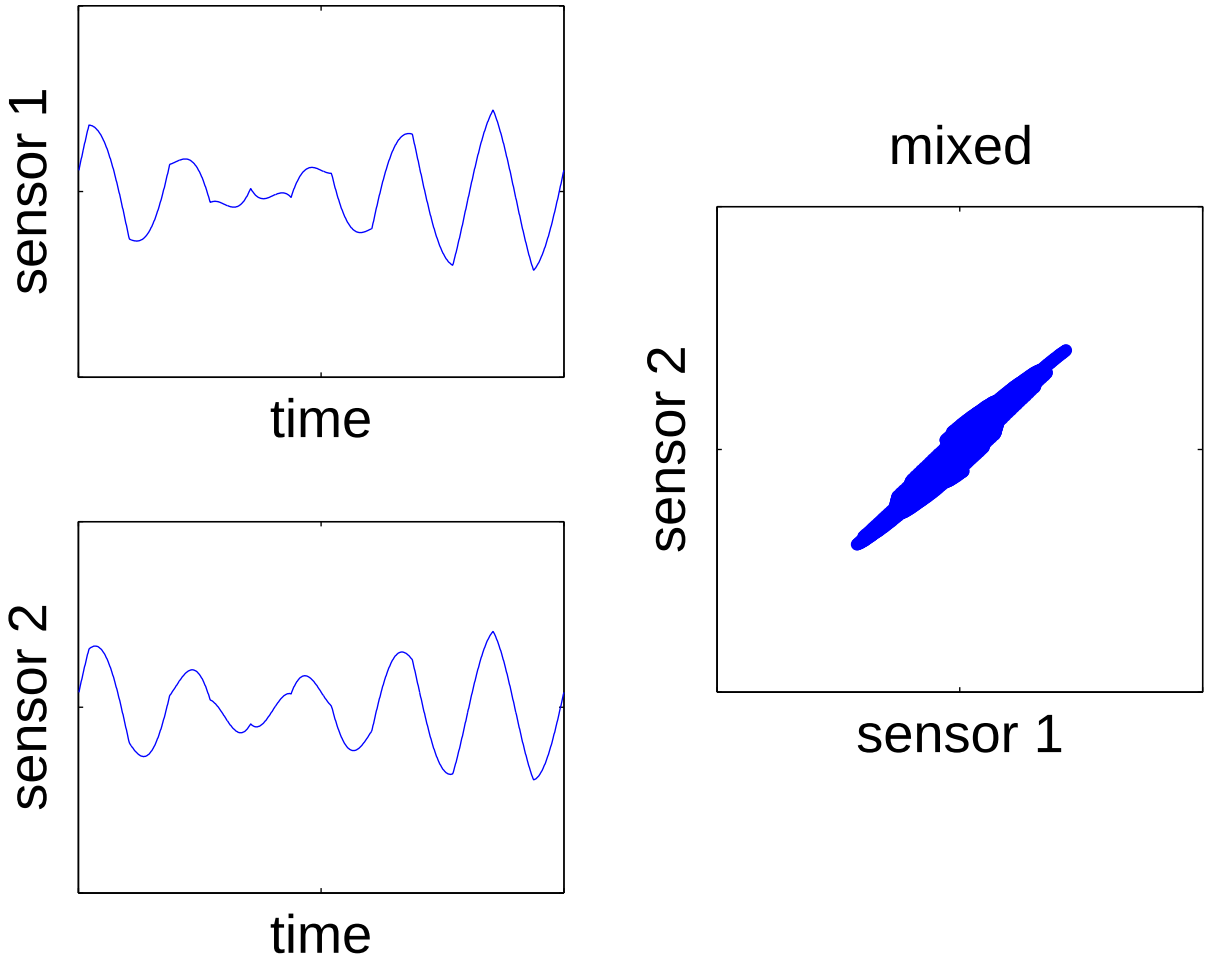


Video: Emotiv.com

Thank you for listening.

Cheap supervised rotation with CSP



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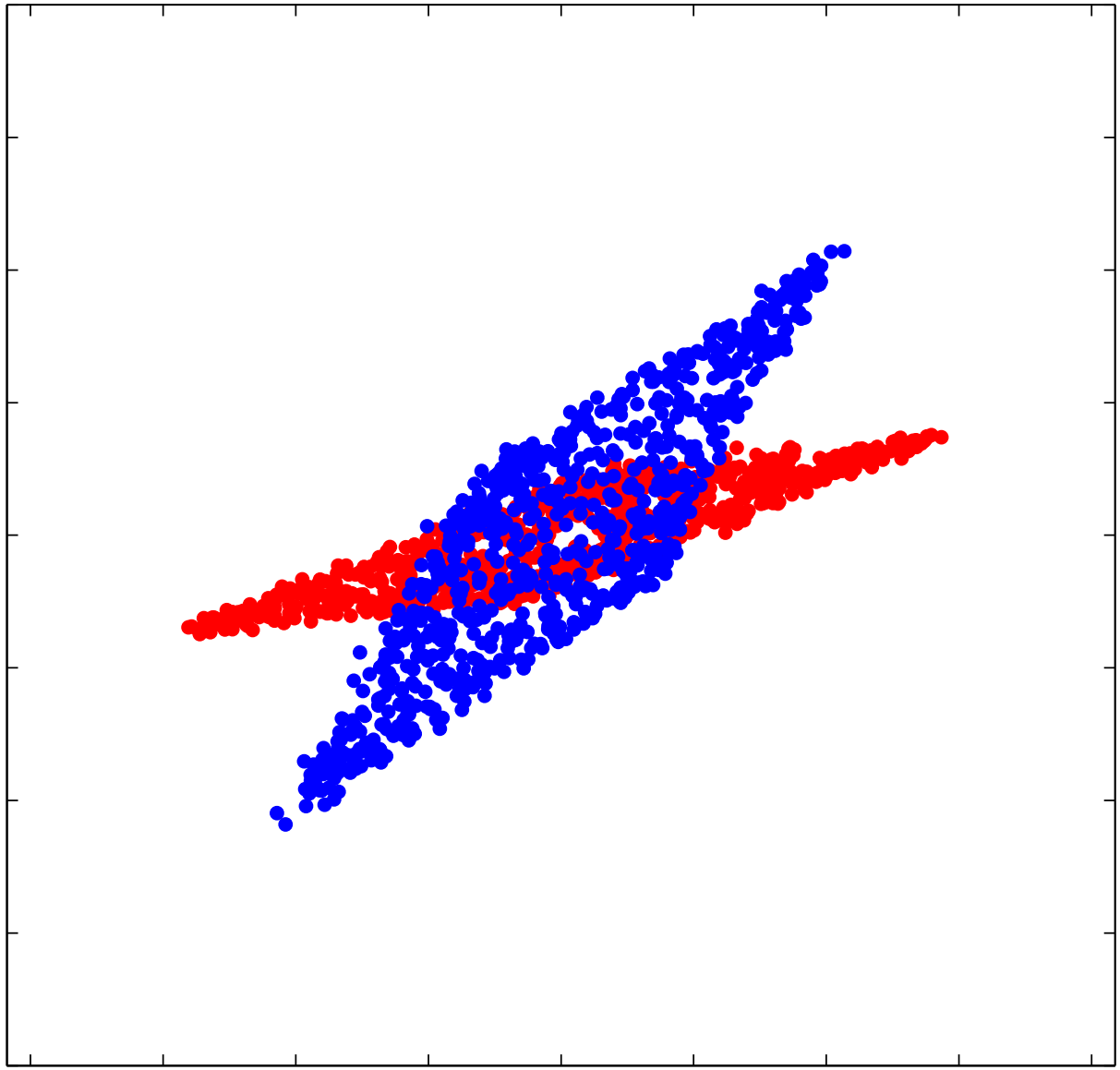

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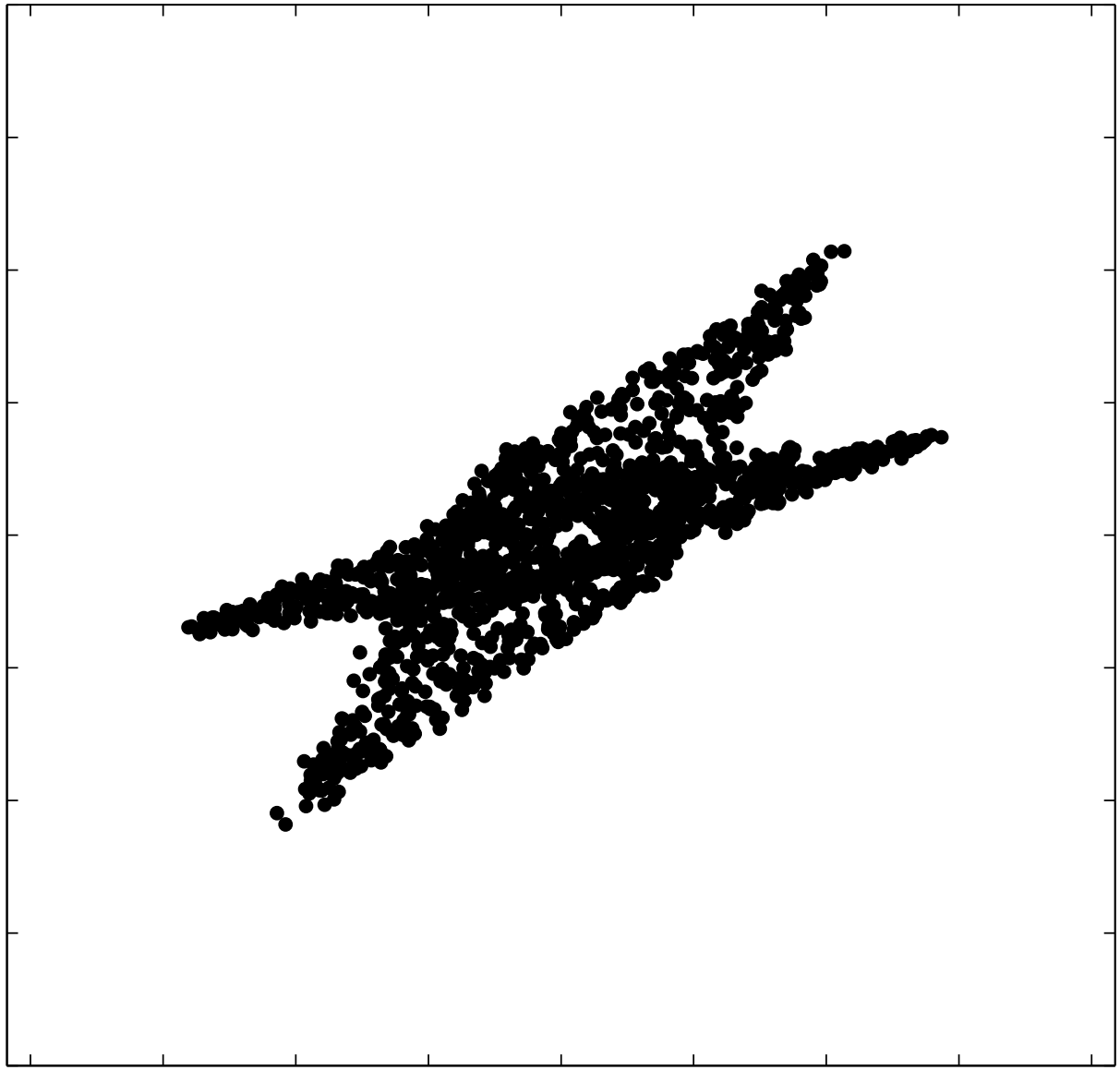

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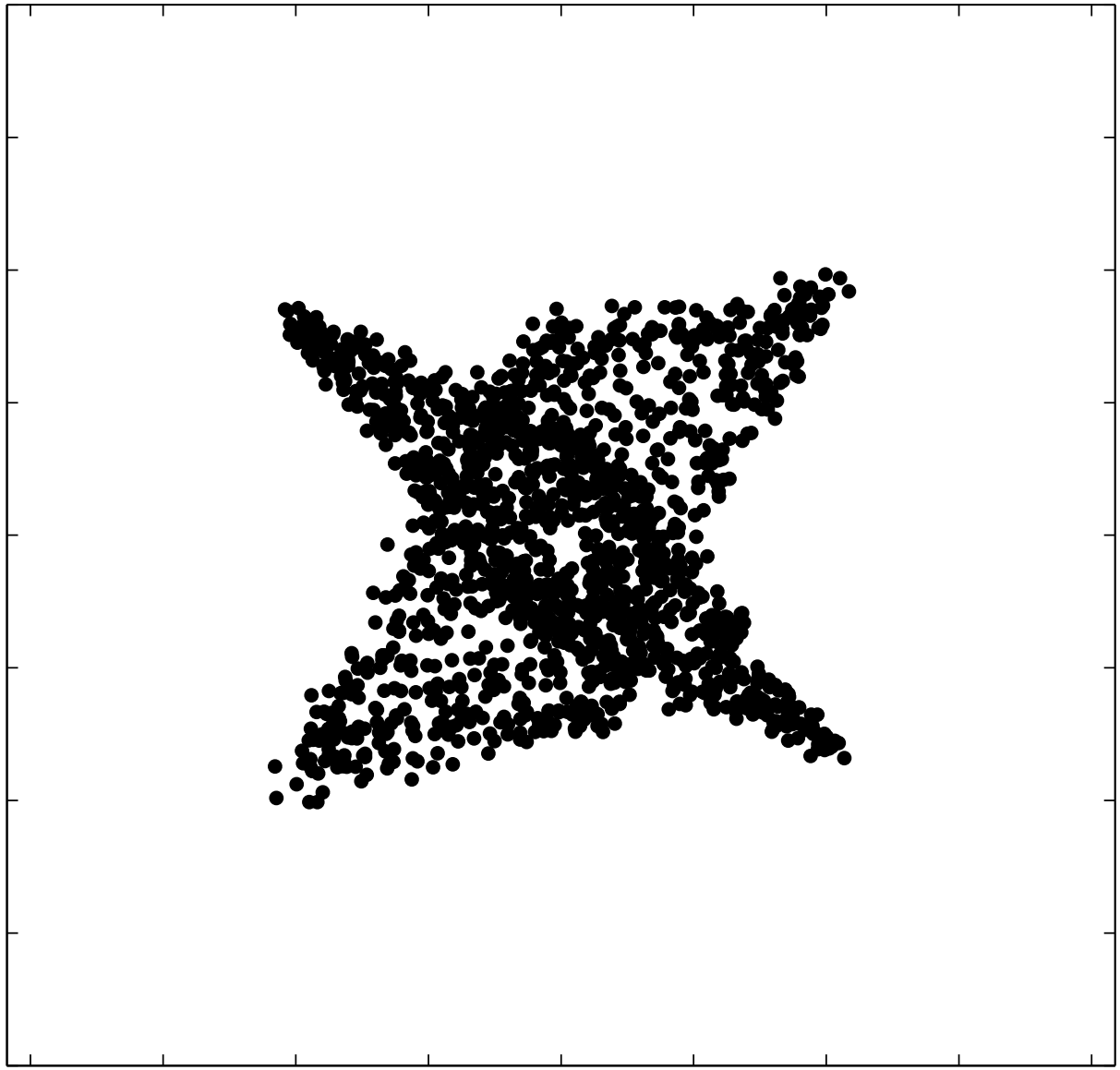

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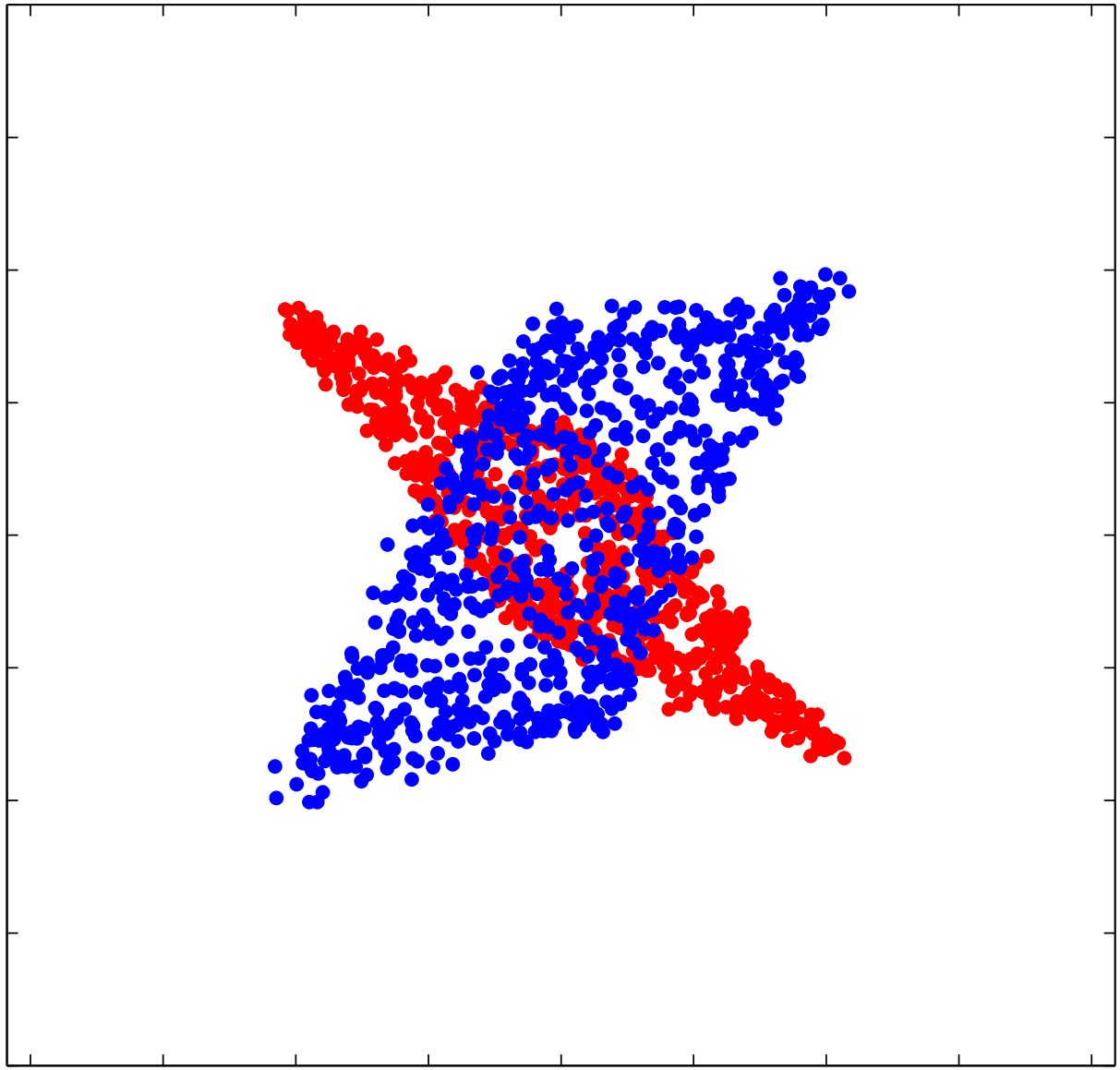

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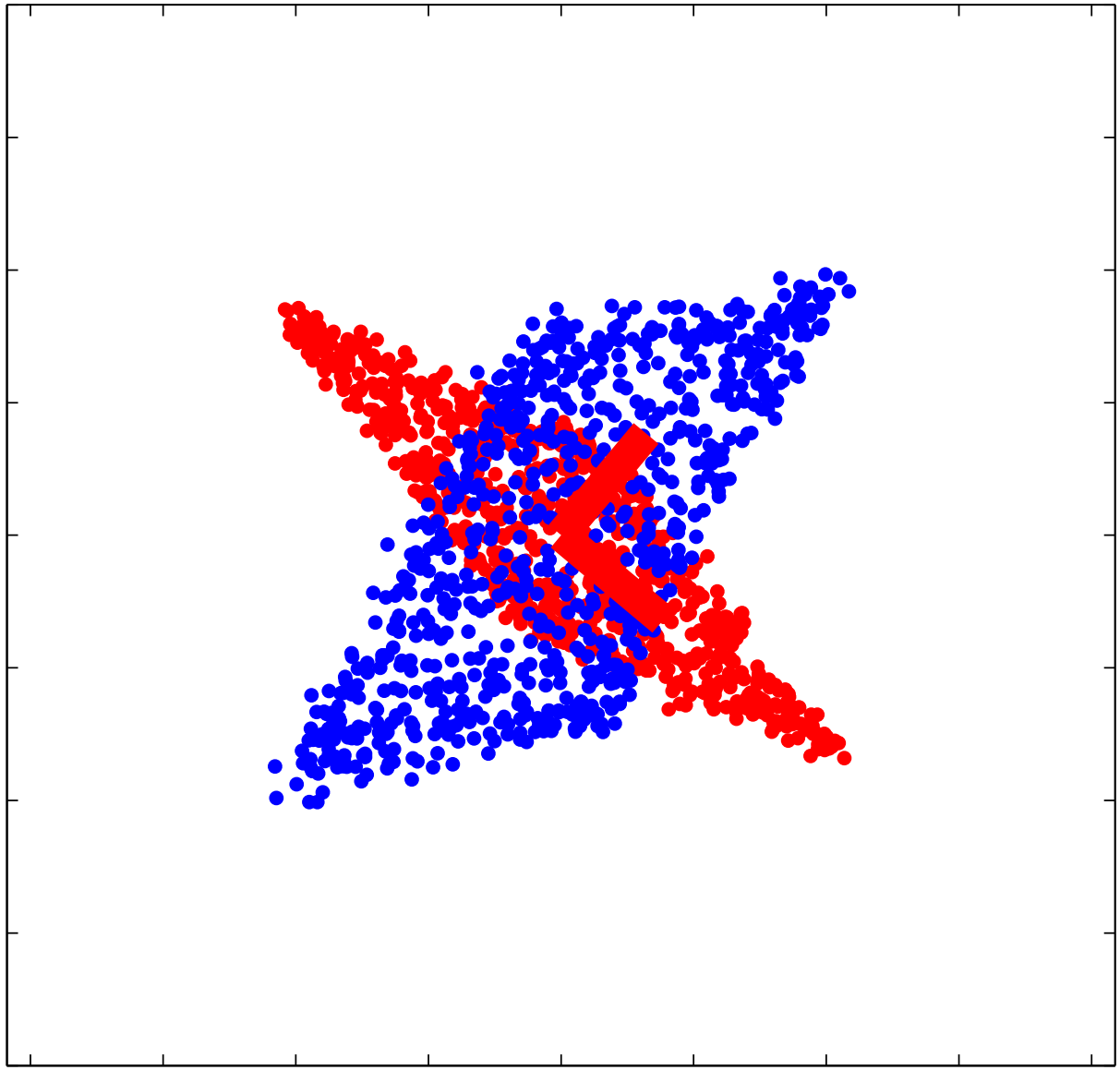

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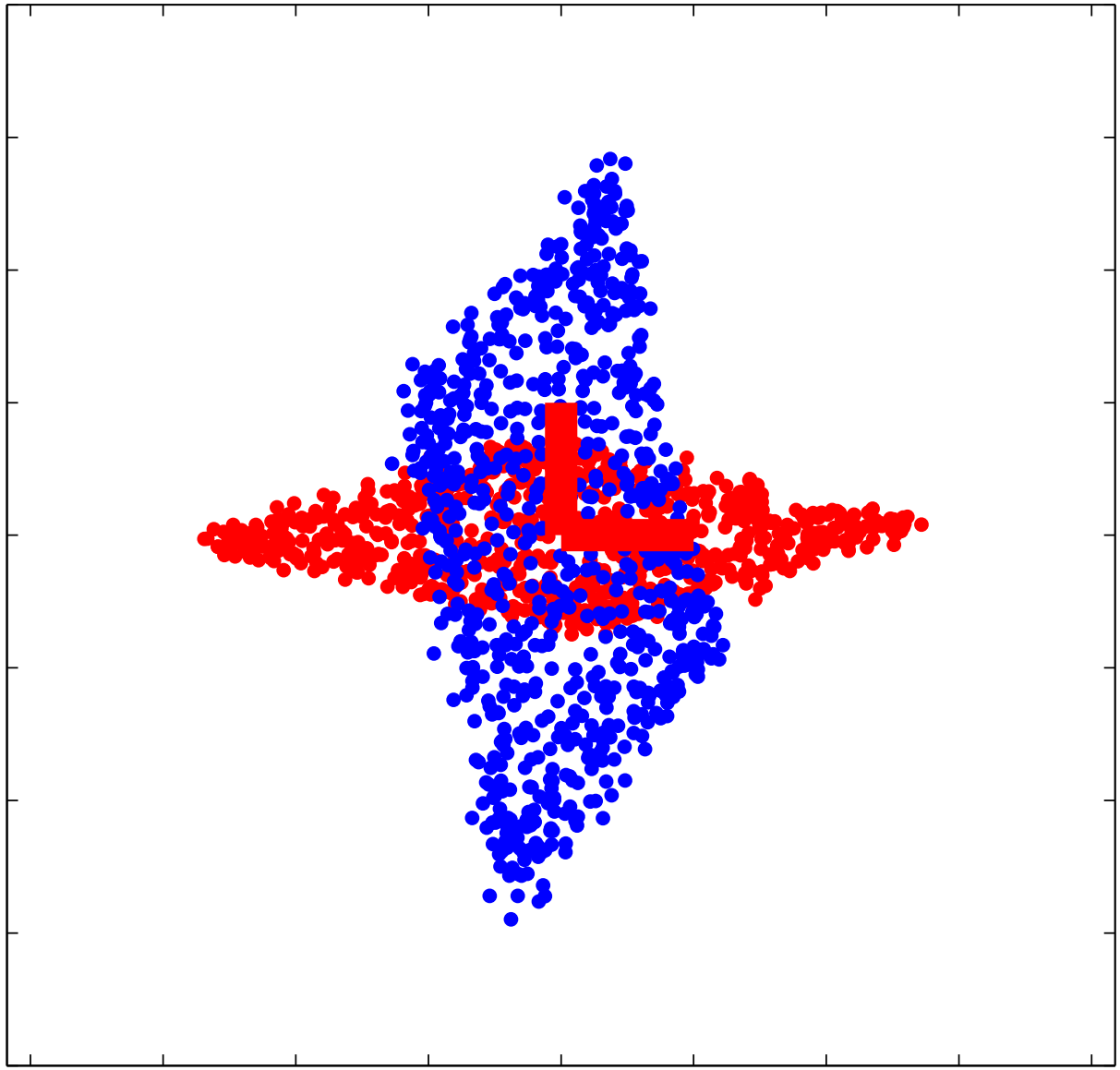
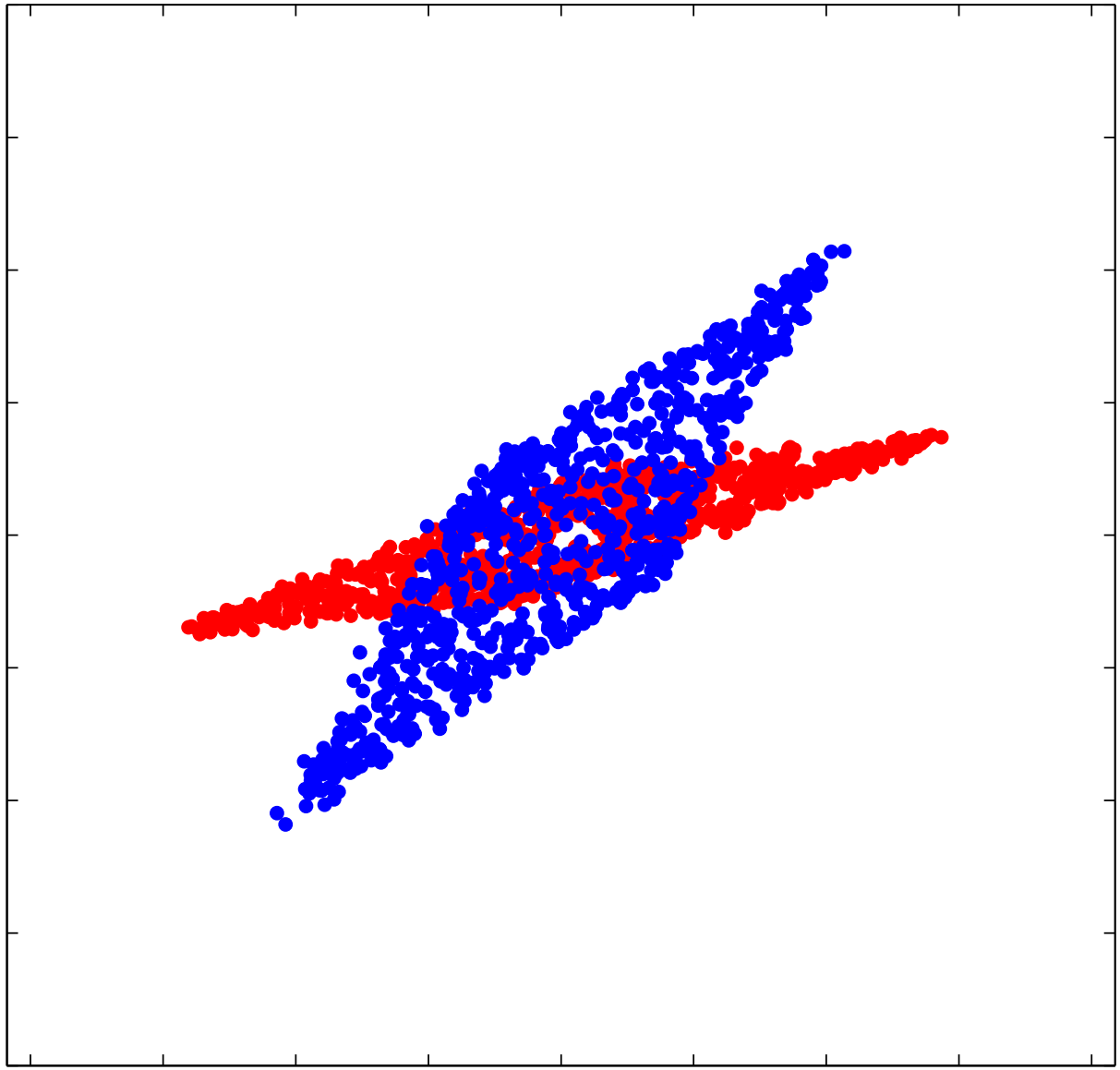


CSP: outlier- (artifact-) sensitivity



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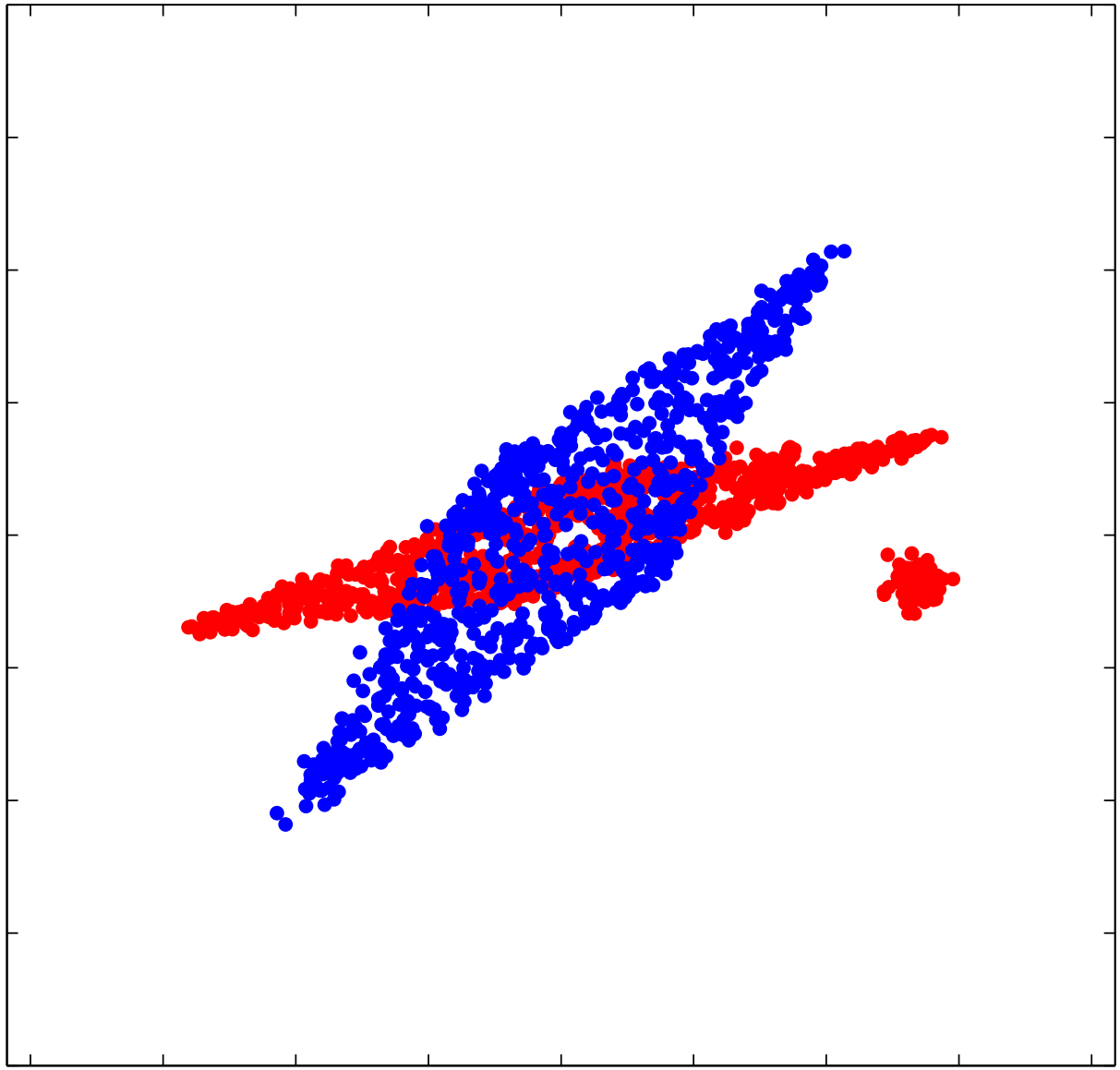

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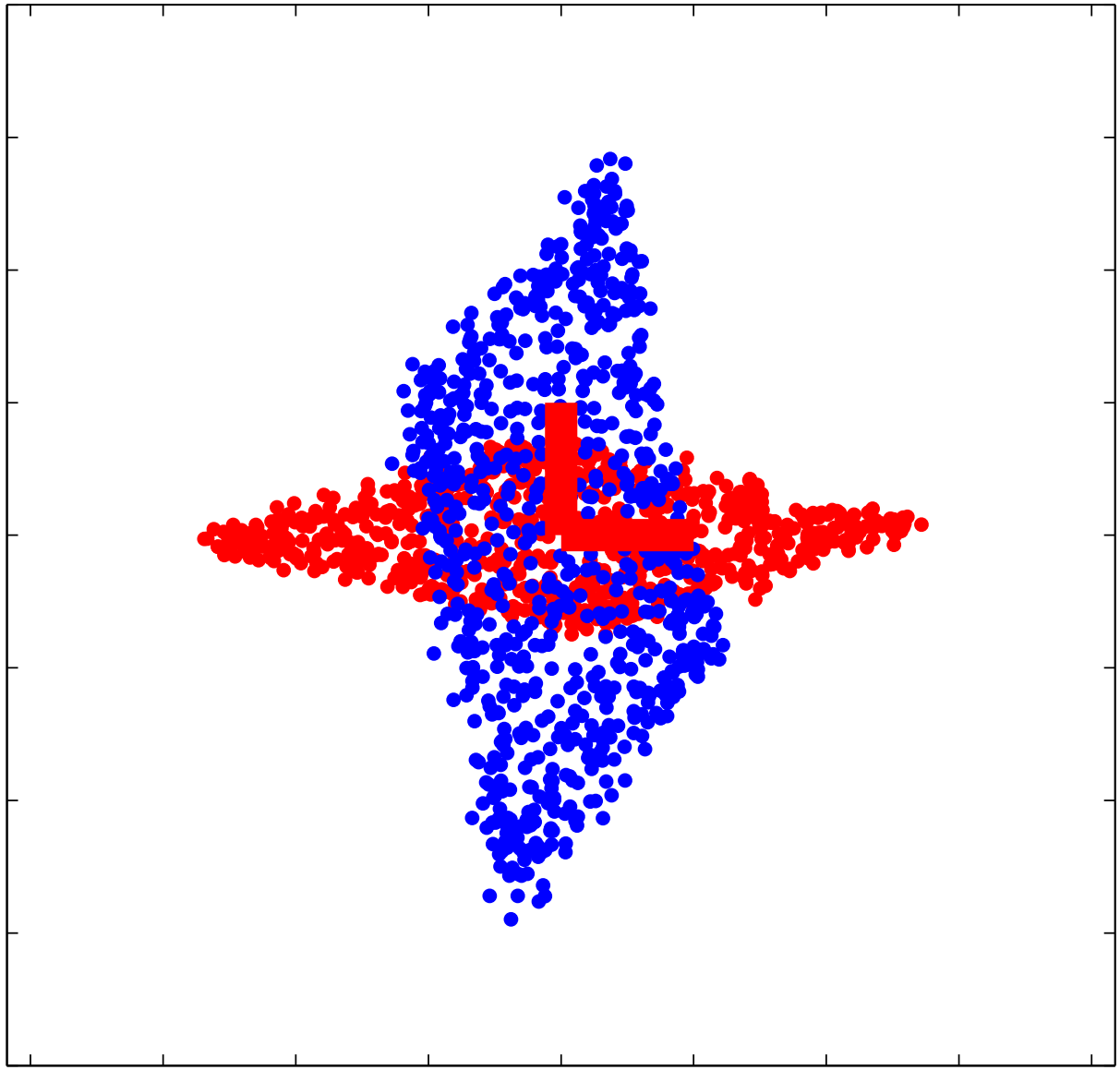

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