K.U.Leuven

The power of Tensor algebra in medical diagnosis

Sabine Van Huffel

Dept. EE, ESAT-SCD

iMinds Future Health Dept

KU Leuven, Belgium

iMinds

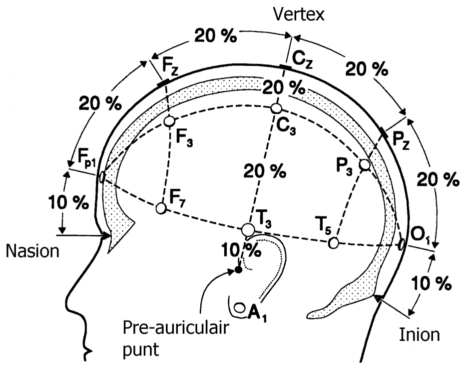
CONNECT.INNOVATE.CREATE

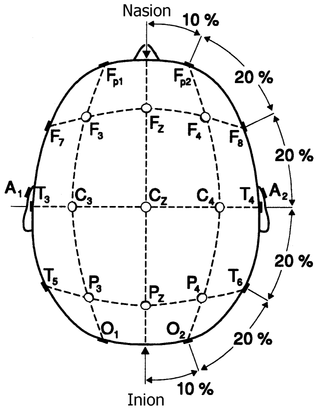
ESAT

Contents Overview

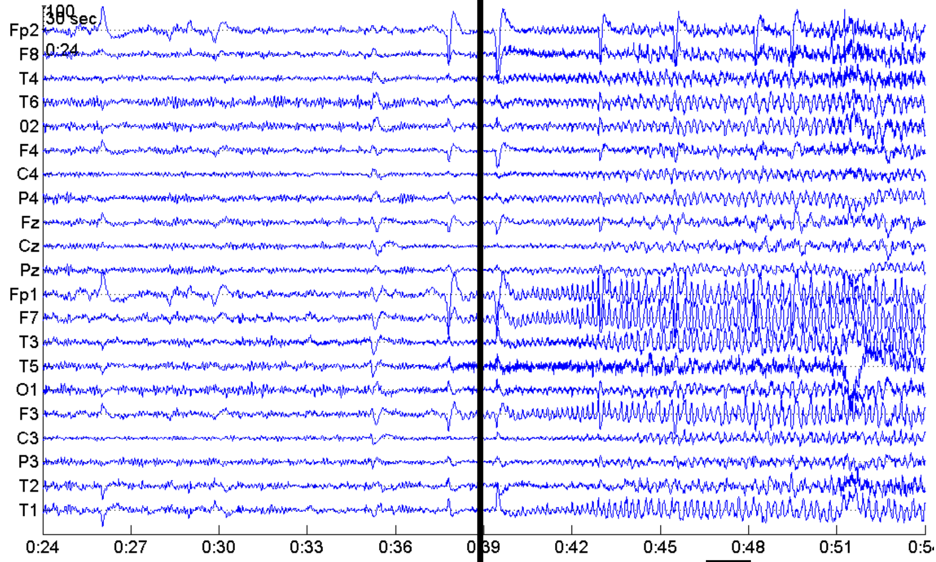
- Introduction
  - EEG and epileptic seizure monitoring
  - Blind Source Separation
- Tensor Algorithms
- Examples in EEG monitoring
- Conclusions and new directions

Introduction: EEG and epileptic seizure monitoring

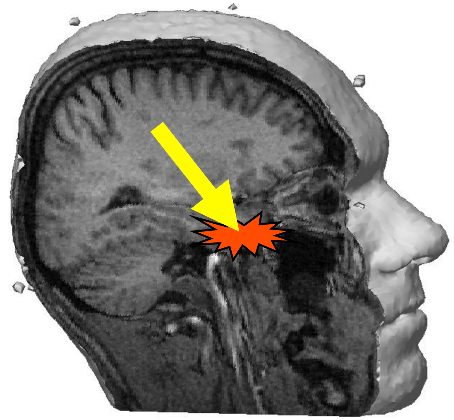




Interictal EEG | Ictal EEG



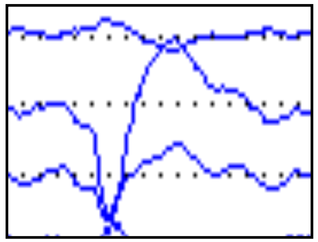
Spikes, slow waves
(epileptiform activity ?)



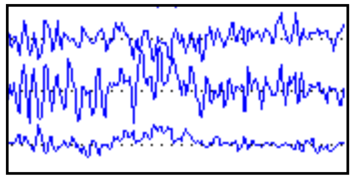
Ictal source localization

artifacts

eye blink



muscle



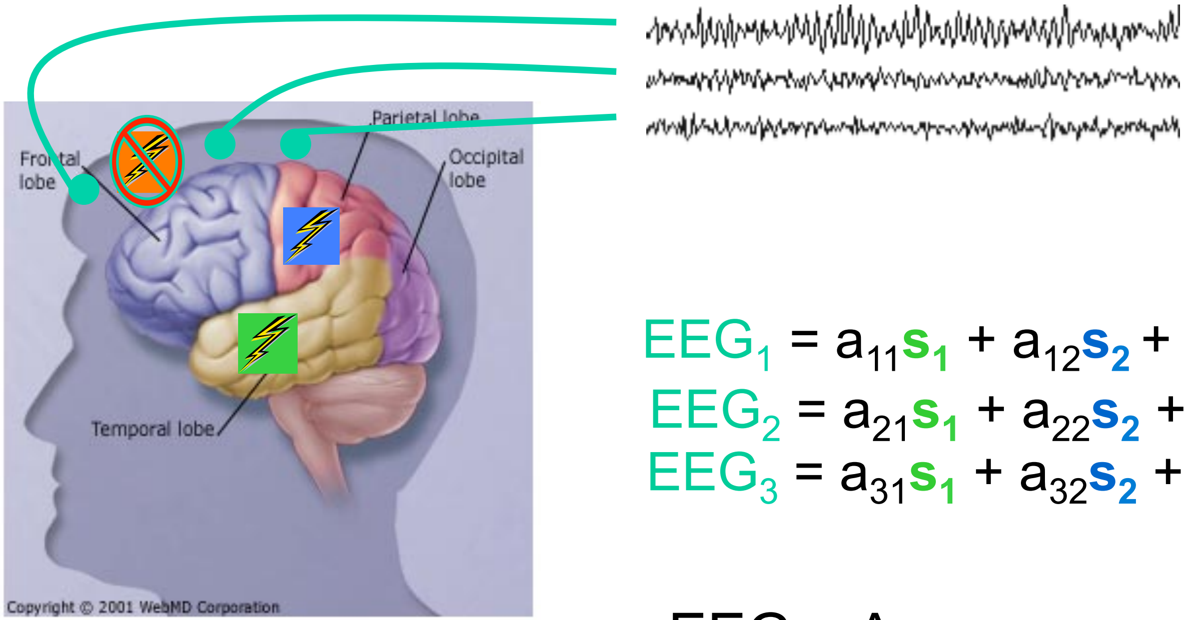
21 electrode positions
@UZ Gasthuisberg

Blind source separation

EEG analysis difficult because of artefacts → REMOVE

Matrix based Blind Source Separation (BSS) → Constraints!

- sources orthogonal (PCA),
- statistically independent (ICA)
- **sources uncorrelated and of different autocorrelation (CCA)**



EEG_1

EEG_2

EEG_3

$$EEG_1 = a_{11}s_1 + a_{12}s_2 + \cancel{a_{13}s_3}$$
$$EEG_2 = a_{21}s_1 + a_{22}s_2 + \cancel{a_{23}s_3}$$
$$EEG_3 = a_{31}s_1 + a_{32}s_2 + \cancel{a_{33}s_3}$$

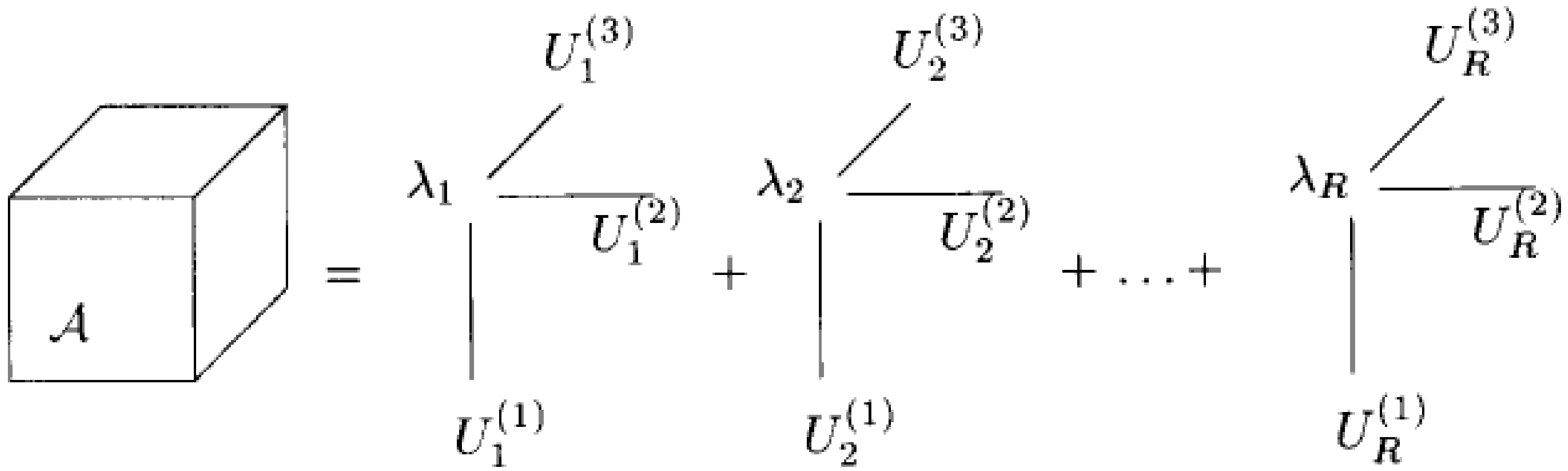
$$EEG = A.s$$

Contents Overview

- Introduction
- Tensor Algorithms
- Examples in EEG monitoring
- Conclusions and new directions

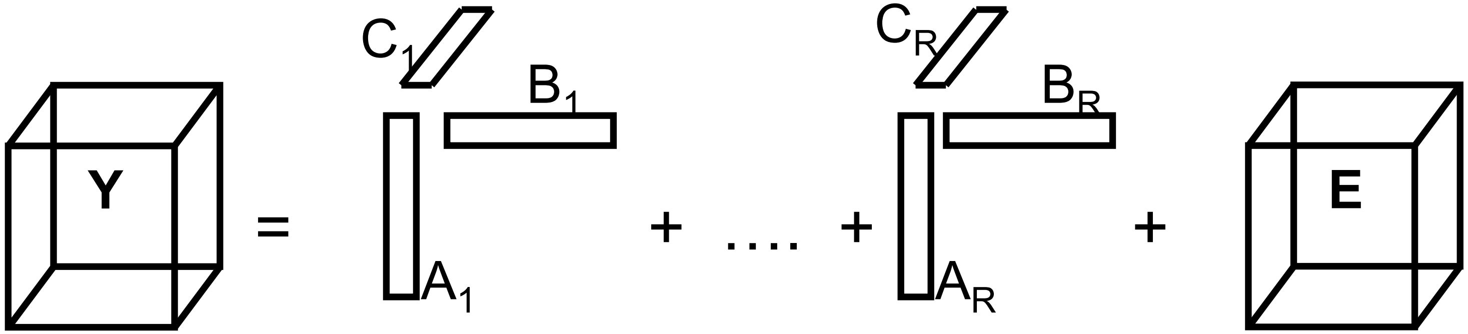
Tensor Algorithms: Canonical Decomposition (PARAFAC)

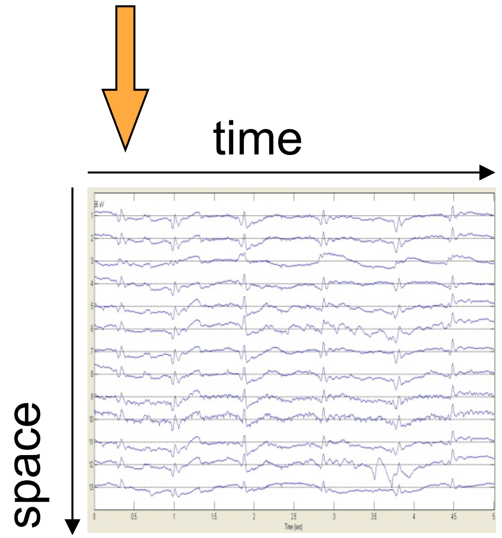
- Advantage for BSS: Tensor Decompositions unique under mild conditions!
- Overviews: P. Comon (talk and papers), Kolda & Bader (SIAM Rev. 2009)
- PARAFAC -> Decomposition into minimal number of (non)orthogonal rank 1 tensors
  - compute via alternating least squares (Smilde, Bro, and Geladi, 2004) → most popular
  - Simultaneous matrix diagonalization/ generalized Schur (De Lathauwer, 2004, 2006)
  - Other schemes (Paatero, 1999; Vorobyov, Sidiropoulos and Gerschman, 2005, …)
  - With orthogonality constraints (Kolda, 2001; Zhang and Golub, 2001)
  - Online PARAFAC (Nion and Sidiropoulos, 2009)
  - Matrix-free Nonlinear Least Squares using Levenberg-Marquardt (Sorber et al,, 2012)



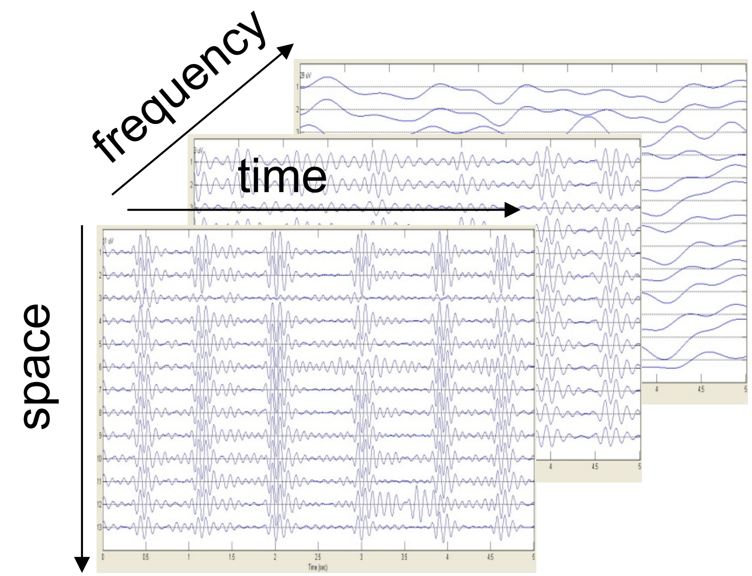
Contents Overview

- Introduction
- Tensor Algorithms
- Examples in EEG monitoring
  - Epileptic seizure onset localization
  - Neonatal seizure localization
  - Event-Related Potential analysis
- Conclusions and new directions





Split EEG in different frequencies using wavelets.



=> Analysis in 3 dimensions instead of just 2

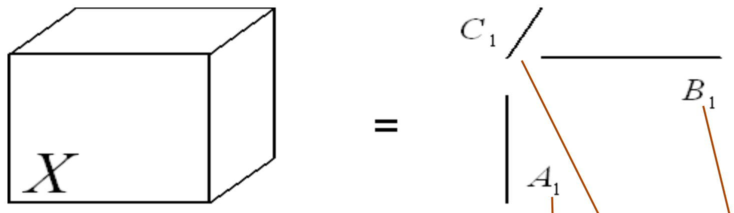
ESAT

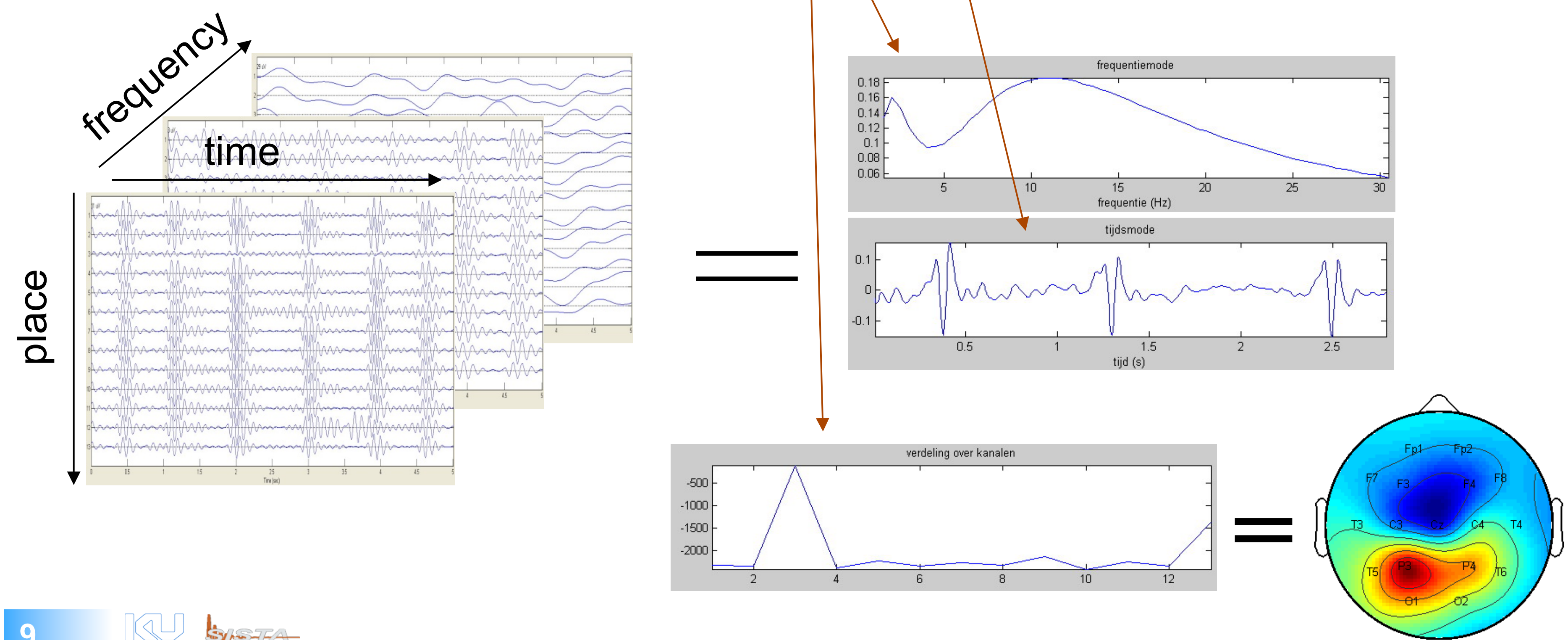
PARAFAC: Example extracting 1 component

B_1: time course

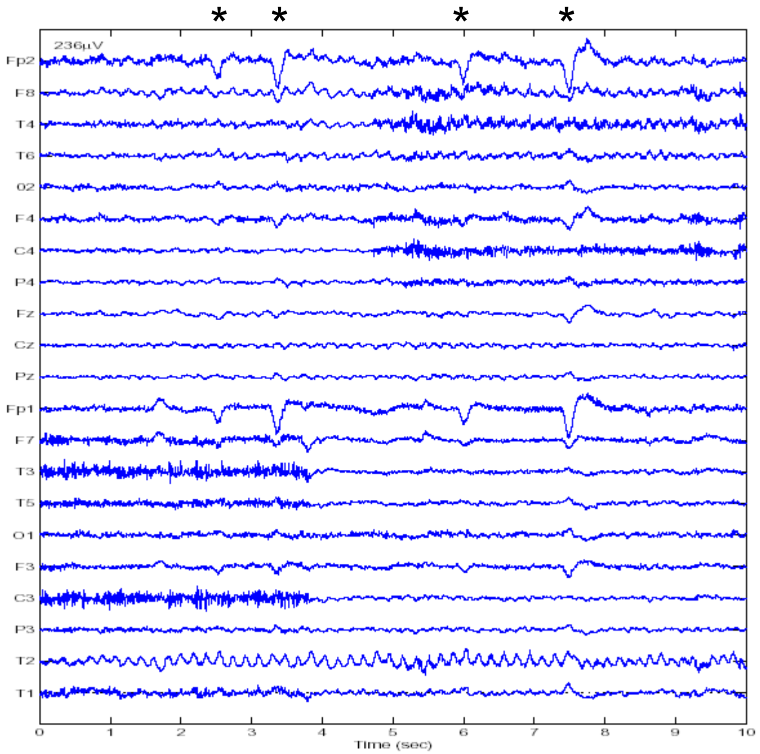
A_1: distribution over channels

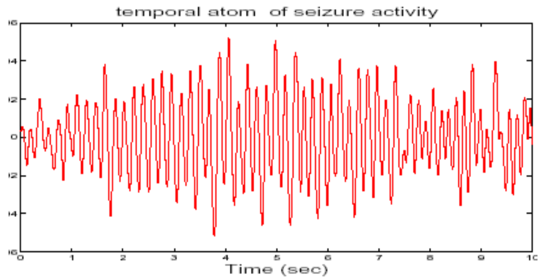
C_1: frequency content (distribution across scales).



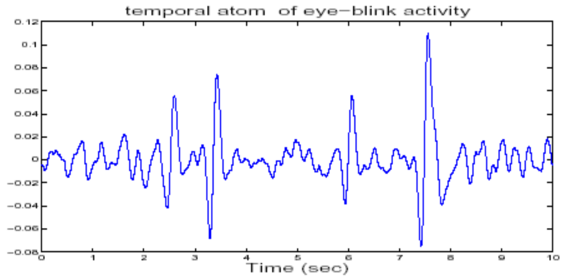


LEUVEN SISTA

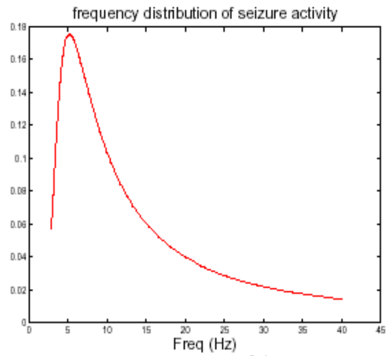




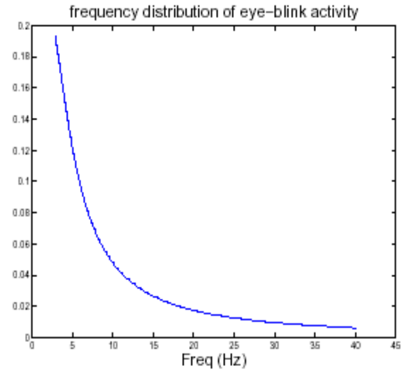
$\mathbf{B}_1$



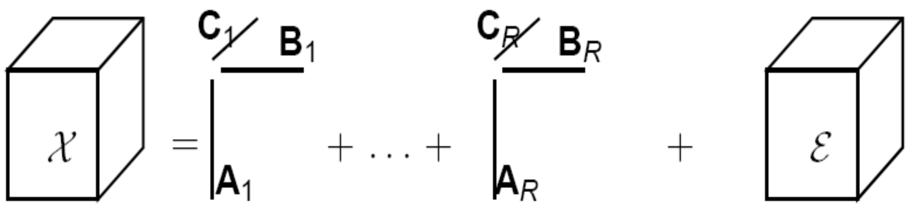
$\mathbf{B}_2$

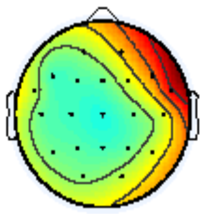


$\mathbf{C}_1$

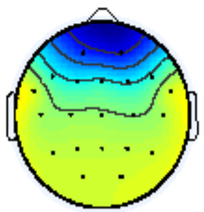


$\mathbf{C}_2$



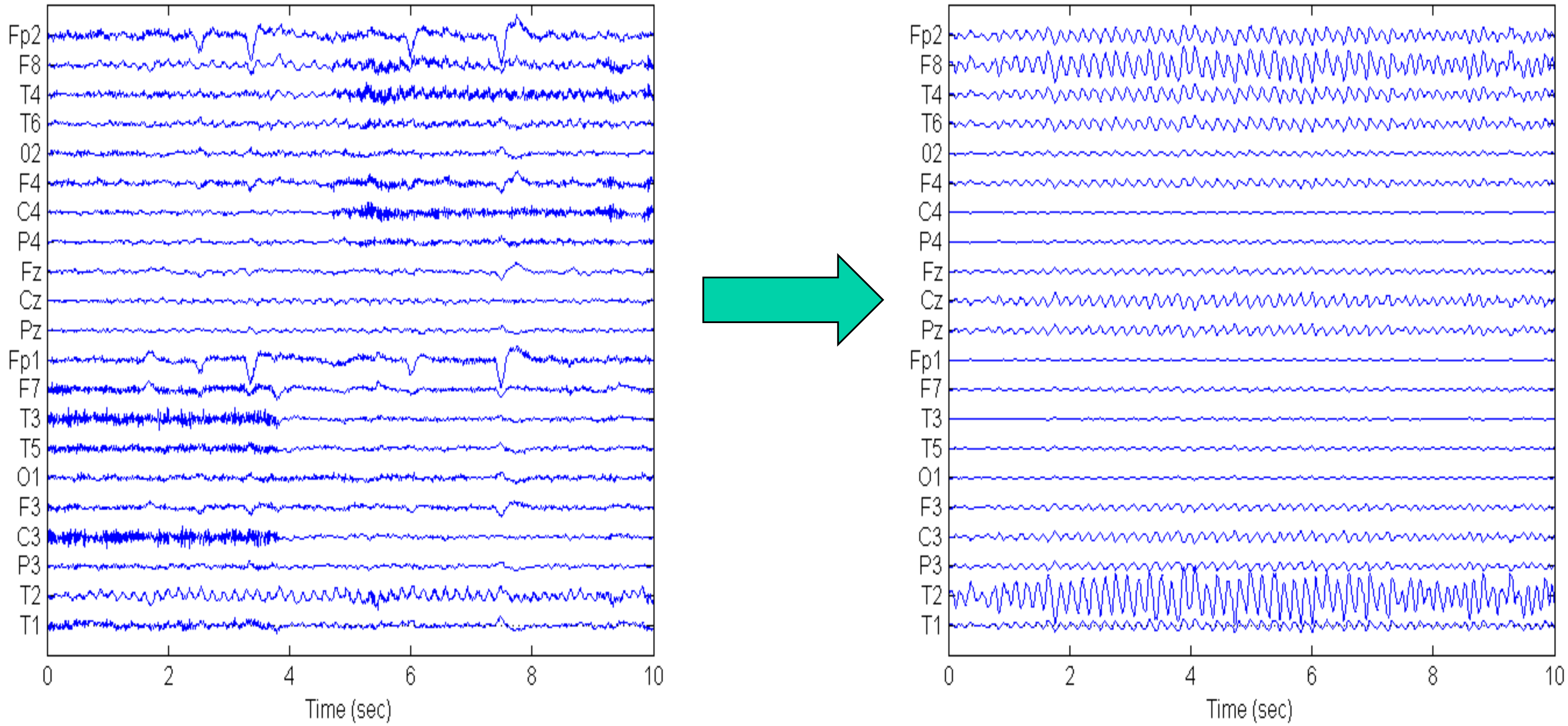


$\mathbf{A}_1$



$\mathbf{A}_2$

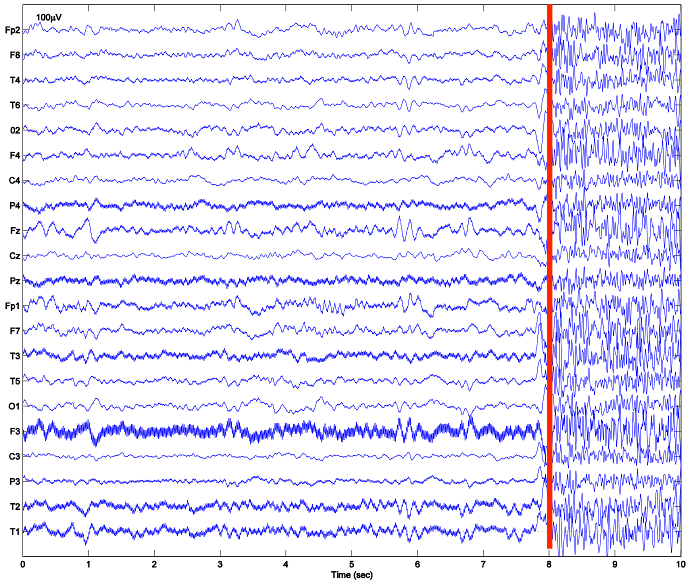
Reconstructed epileptic atom



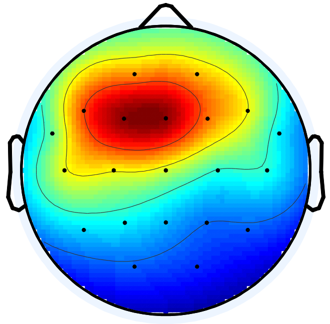
(De Vos et al., NeuroImage 2007) (E. Acar et al, Bioinformatics 2007)

More interesting seizure

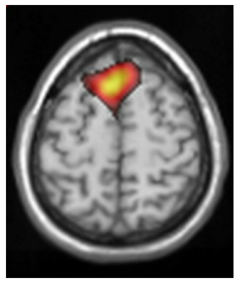
A



B

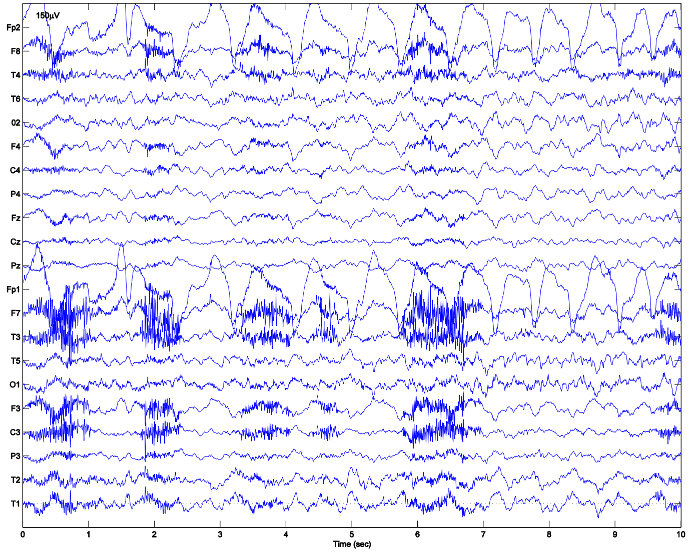


C

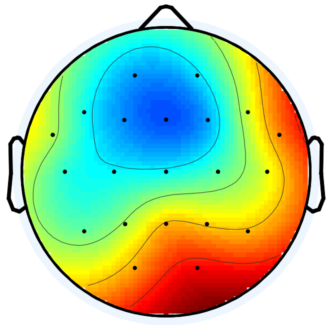


More interesting seizure

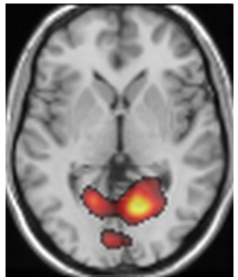
A



B



C



Why does this work?

- Muscle artifacts are distributed over frequencies by wavelet transformation and can not be modeled by a trilinear structure

- In 2 (or 10) seconds, seizures are stable in time, frequency and space

- PARAFAC is ``unique’’

Added value in clinical practice?

Validation study with UZ Leuven→ ictal EEG of 37 patients

- Visual analysis : 21 well localized
- New method: 34 well localized

PARAFAC:

→ separates ictal atom from background EEG

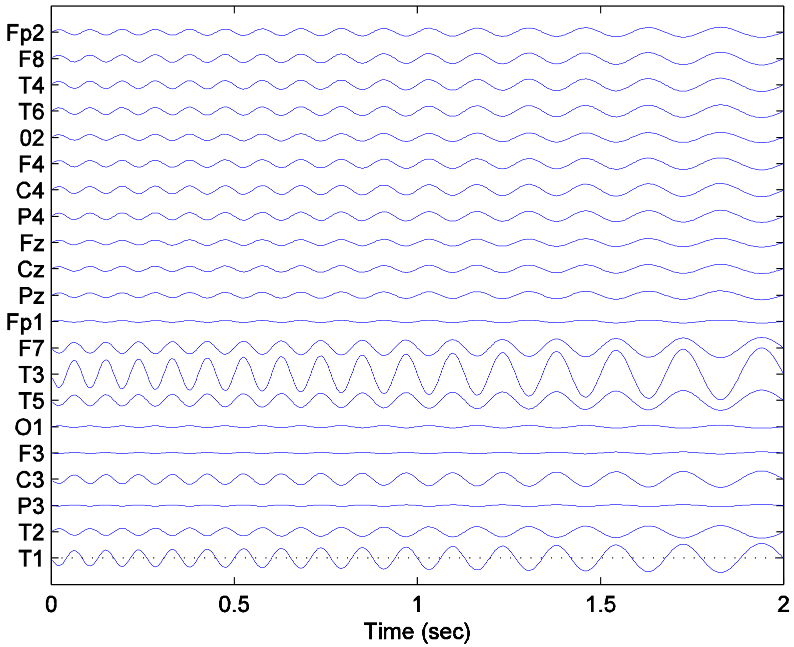
→ is more reliable than visual analysis and matrix techniques (ICA, SVD) for seizure onset localization

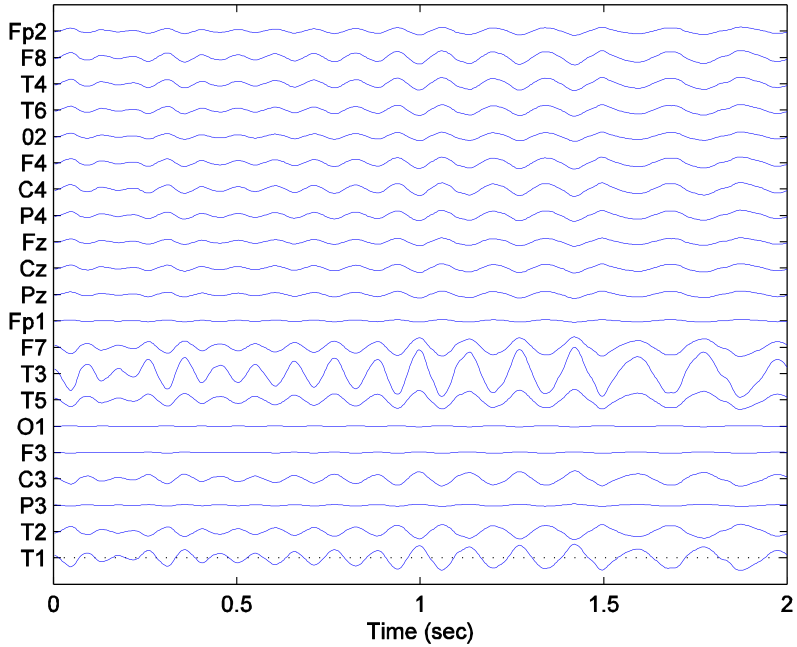
→ can be used as preprocessing step for source localization

ESAT

Limits of a trilinear model

- A sinusoidal signal gives rise to a perfect trilinear model after wavelet transforming,
- But what happens if the frequency changes during the analyzed time interval?
- We simulated a chirp, added noise and localised the epileptic EEG





Limits of a trilinear model

- Signal is not perfectly recovered (as expected)
- But it is still well localized!

- Introduction
- Tensor Algorithms
- Examples in EEG monitoring
  - Epileptic seizure onset localization
  - Neonatal seizure localization
  - Event-Related Potential Analysis
- Conclusions and new directions

Neonatal brain monitoring → seizure detection

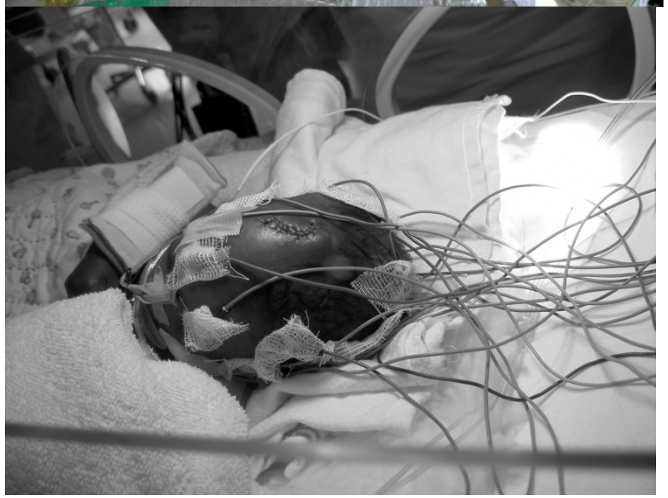
Lack of oxygen supply leads to brain damage

The occurrence of seizures best indicator for neurological damage and can increase damage if not properly treated

Most seizures subclinical (90%): only detectable via EEG monitoring.

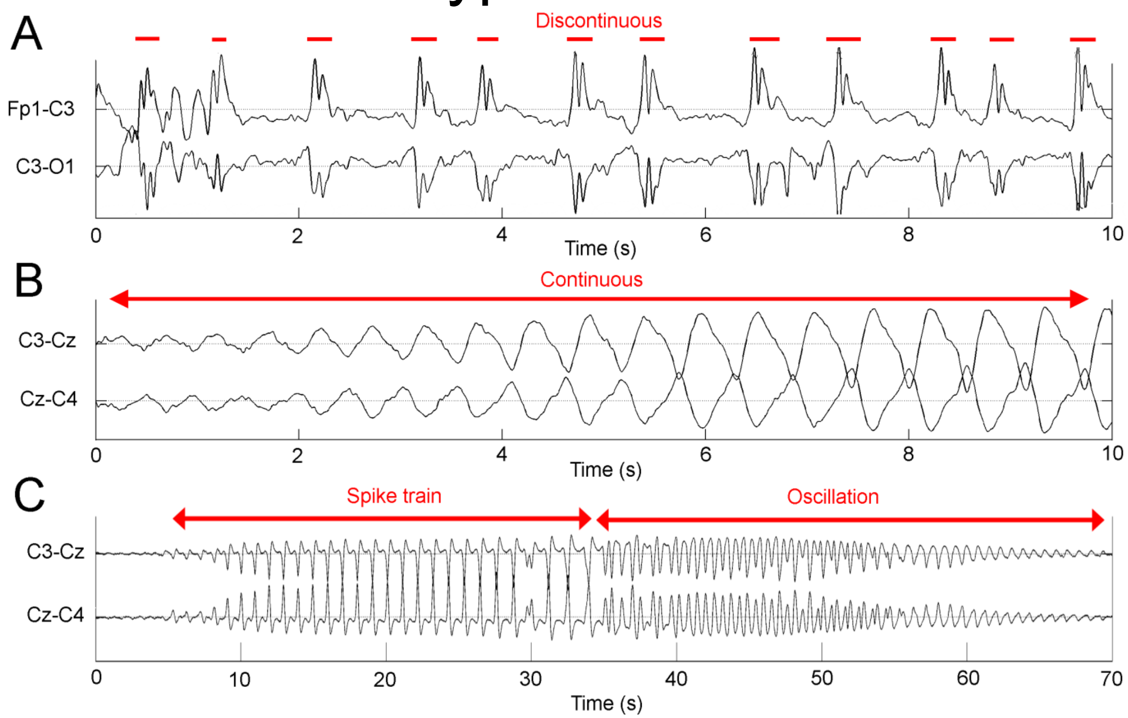
→ ***Need for automated EEG monitoring***.
Collaboration with Sophia Child Hospital, Rotterdam, NL

In the USA:
- 1 on 8 births premature
- 11.1% of prematures have seizures



Algorithm, mimicking the human observer :
(Deburchgraeve et al., Clinical Neurophysiology 2008 & 2009)

2 seizure types:



Spike train

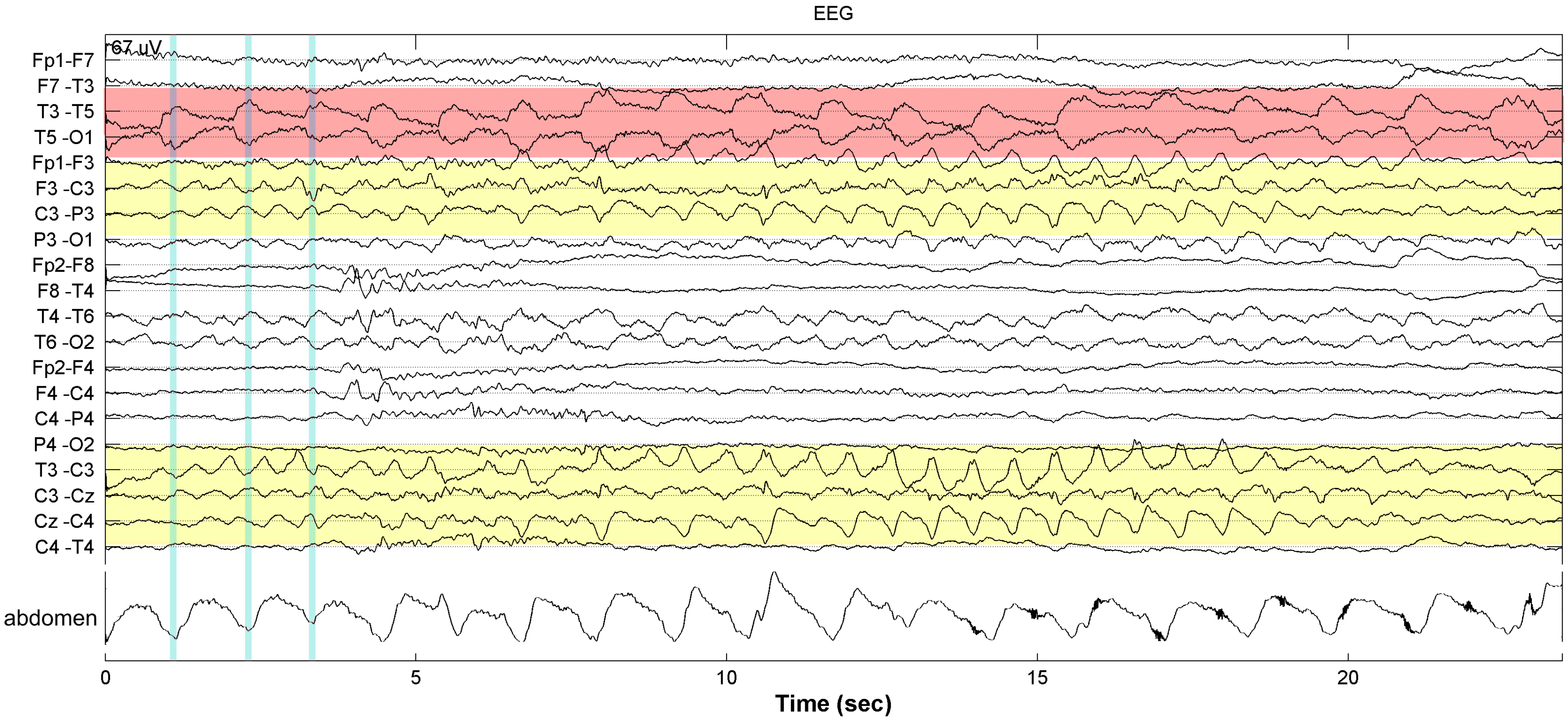
Oscillation

Combination

For each type a separate detection algorithm was developed.

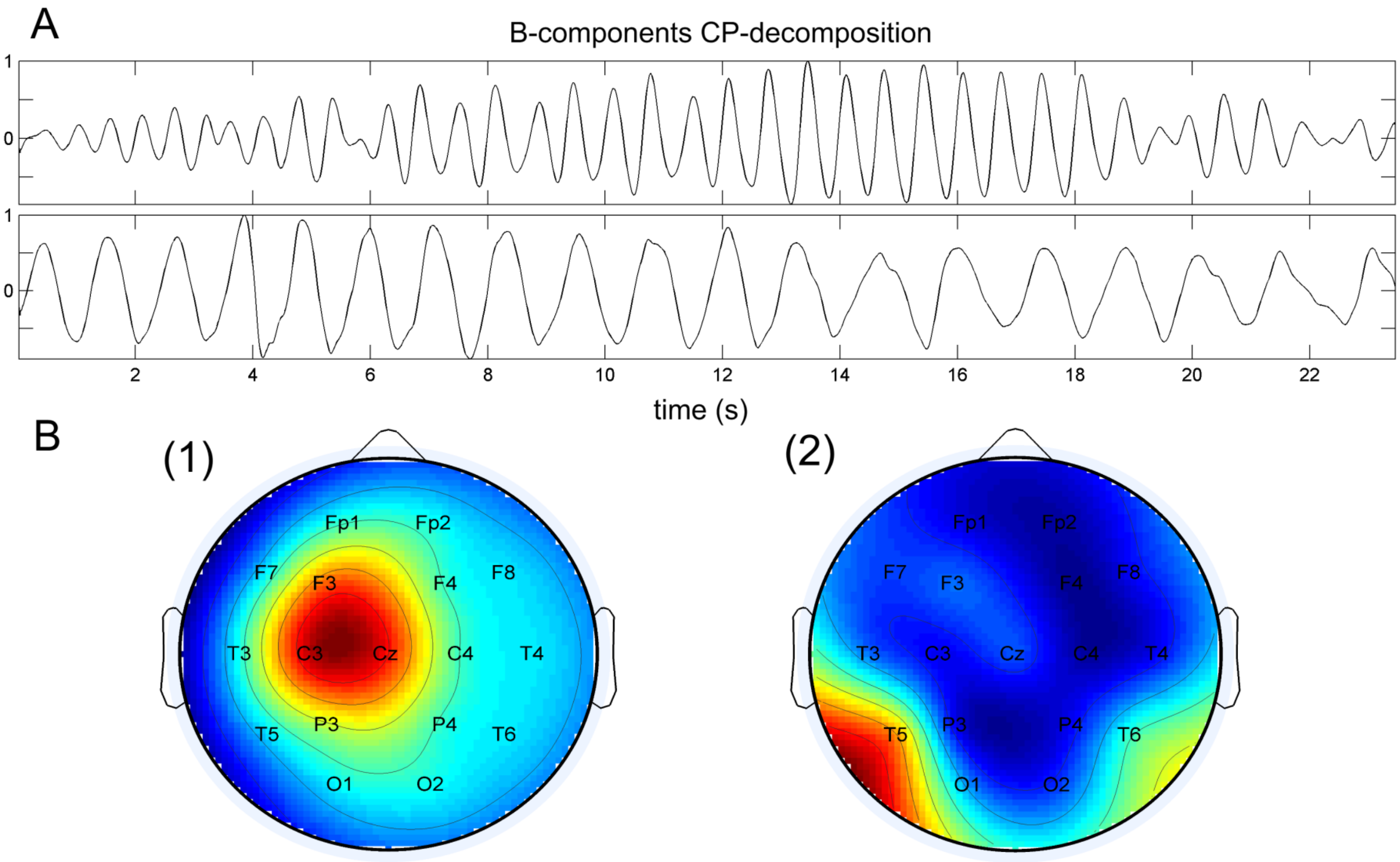
Extract & localize oscillations using PARAFAC

Seizure on C3-Cz-F3 + artefact on T5



$\Rightarrow$ O-CP: Extract spatial distribution of the seizure without distortion of the artifact.

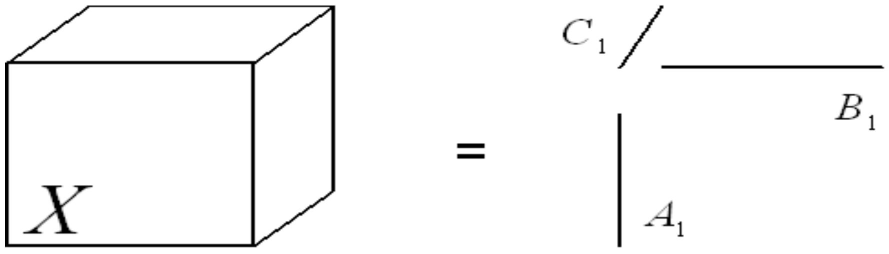
Extract & localize oscillations using PARAFAC



Why trilinear structure to extract oscillation?

PARAFAC models as much variance as possible in the tensor that fits in a trilinear structure.

⇒ Sensitive for activity that is active during the whole time segment, stable in localization and frequency



⇒ Oscillations in the EEG meet those requirements, thus

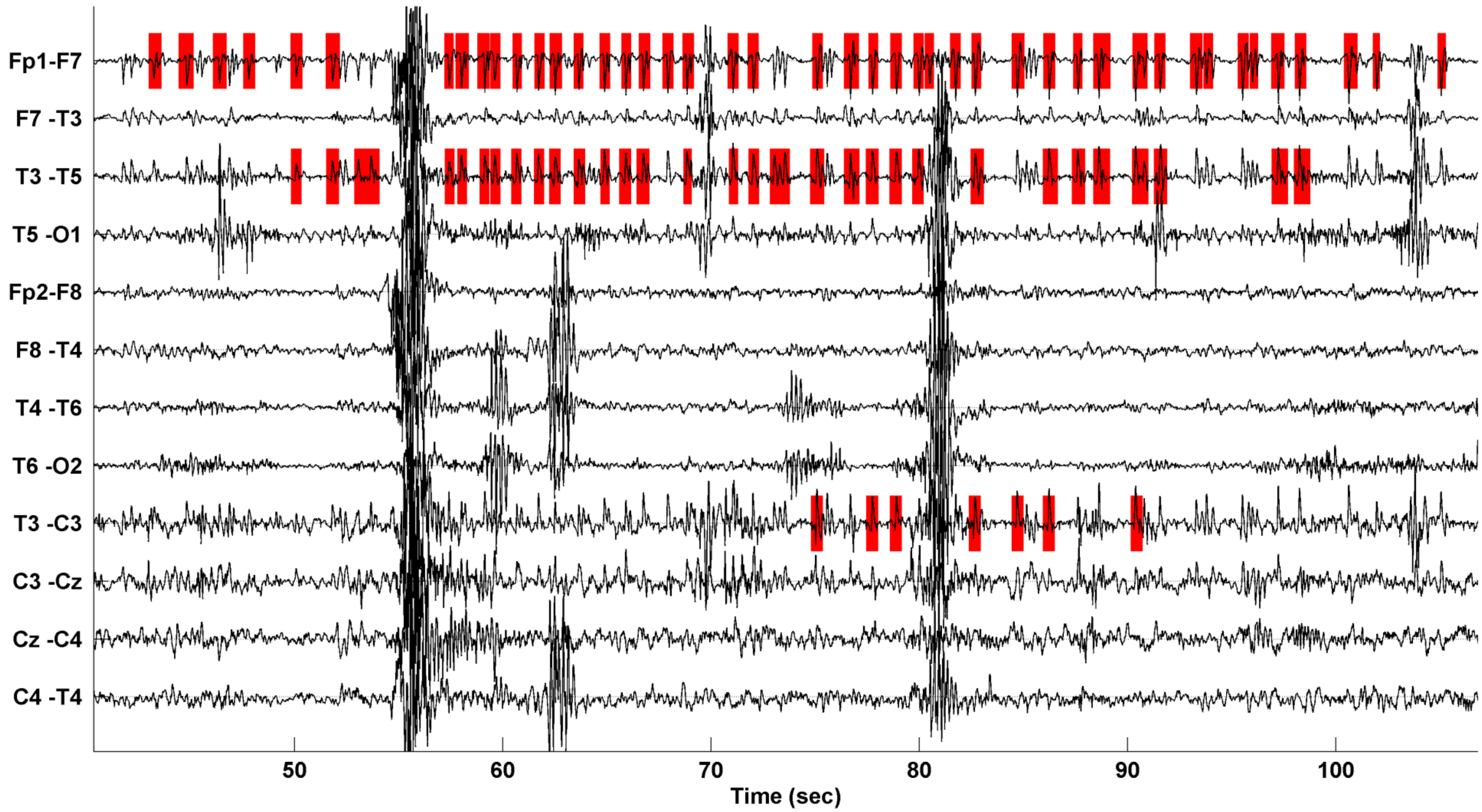
PARAFAC is most sensitive for oscillations in the EEG.

⇒ *Less suitable for spike train type seizures* as they are

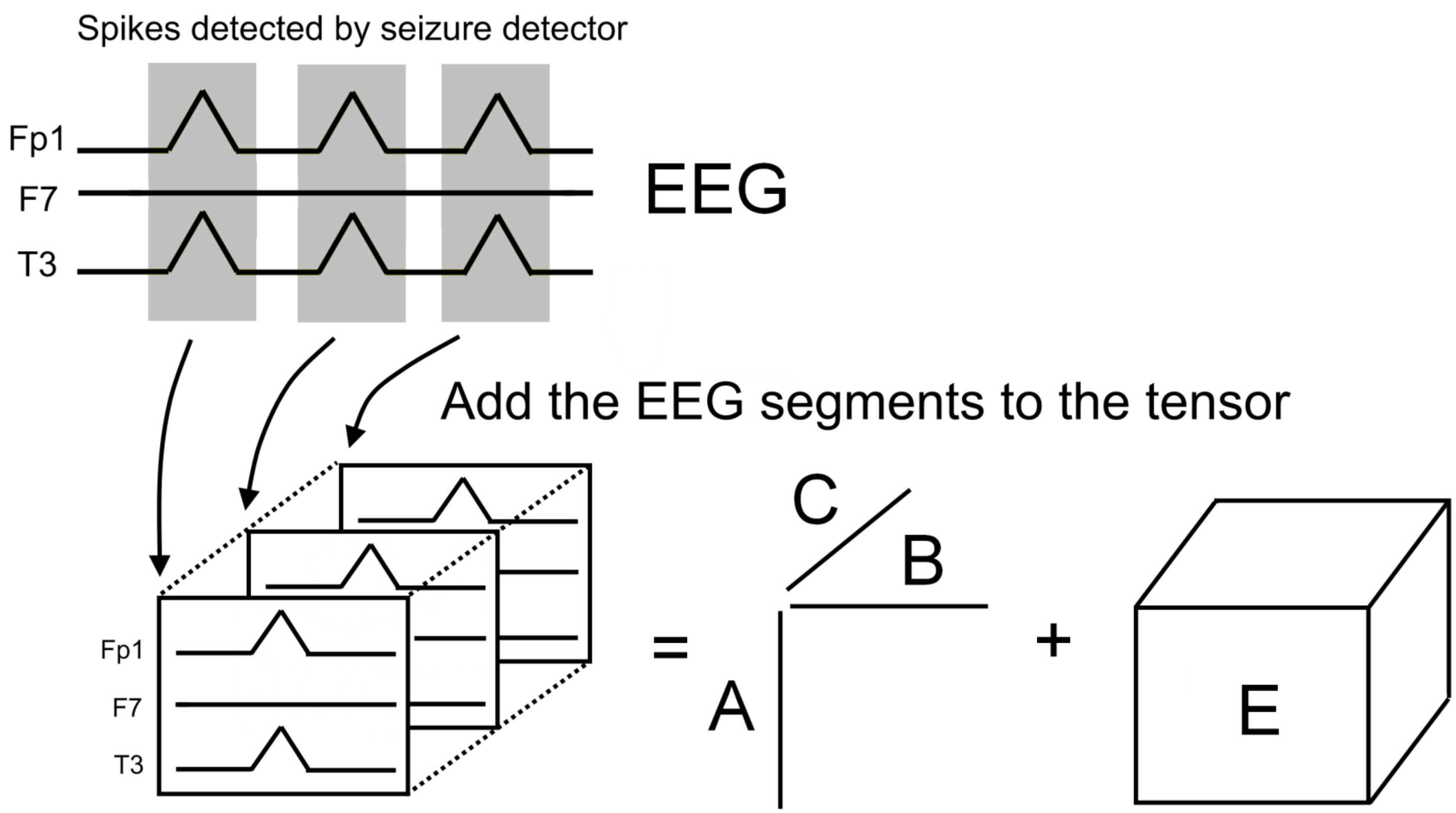
discontinuous and too local in time.

Extract & localize spikes using PARAFAC

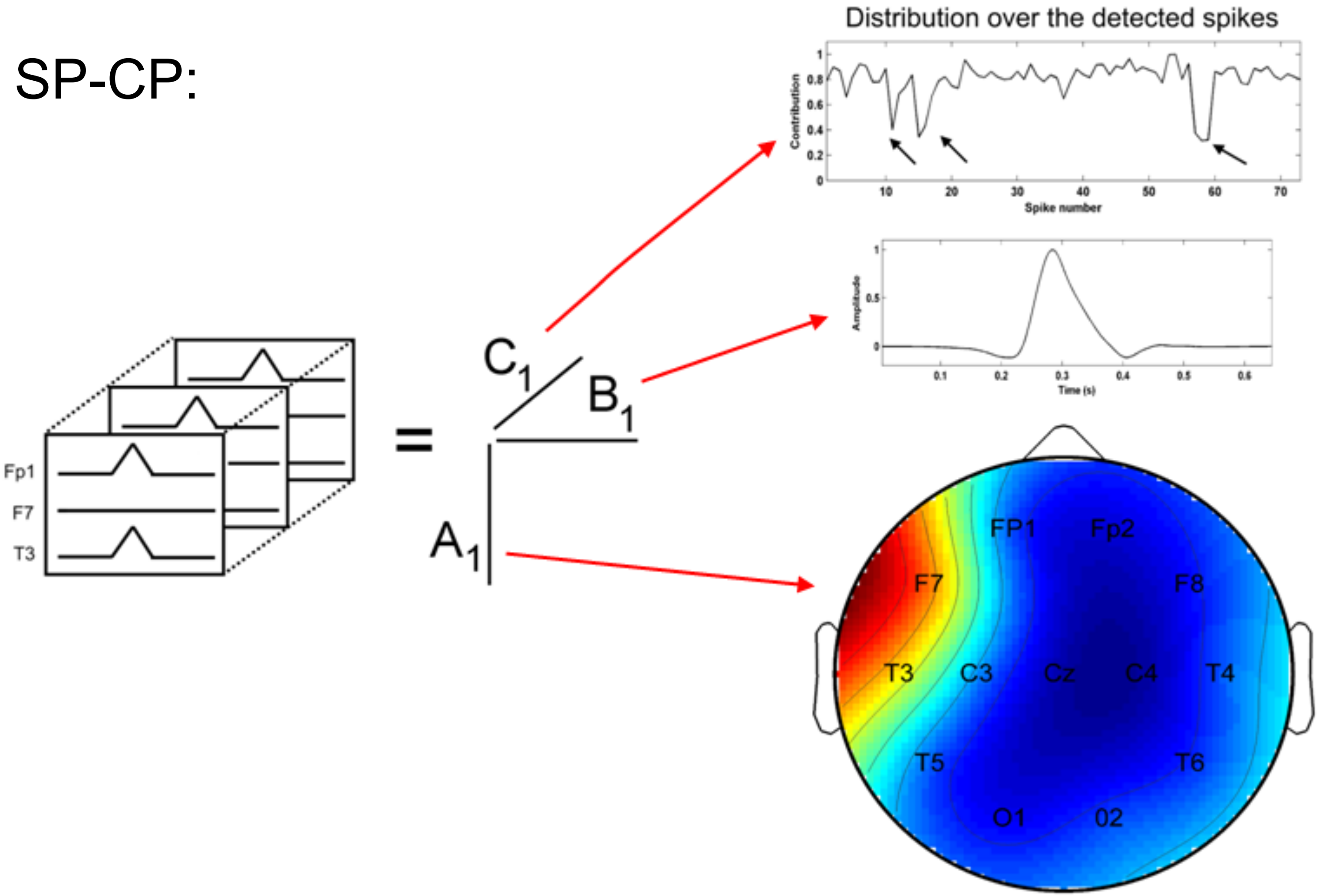
We use the output of the seizure detector:



Construction of the tensor:



SP-CP:

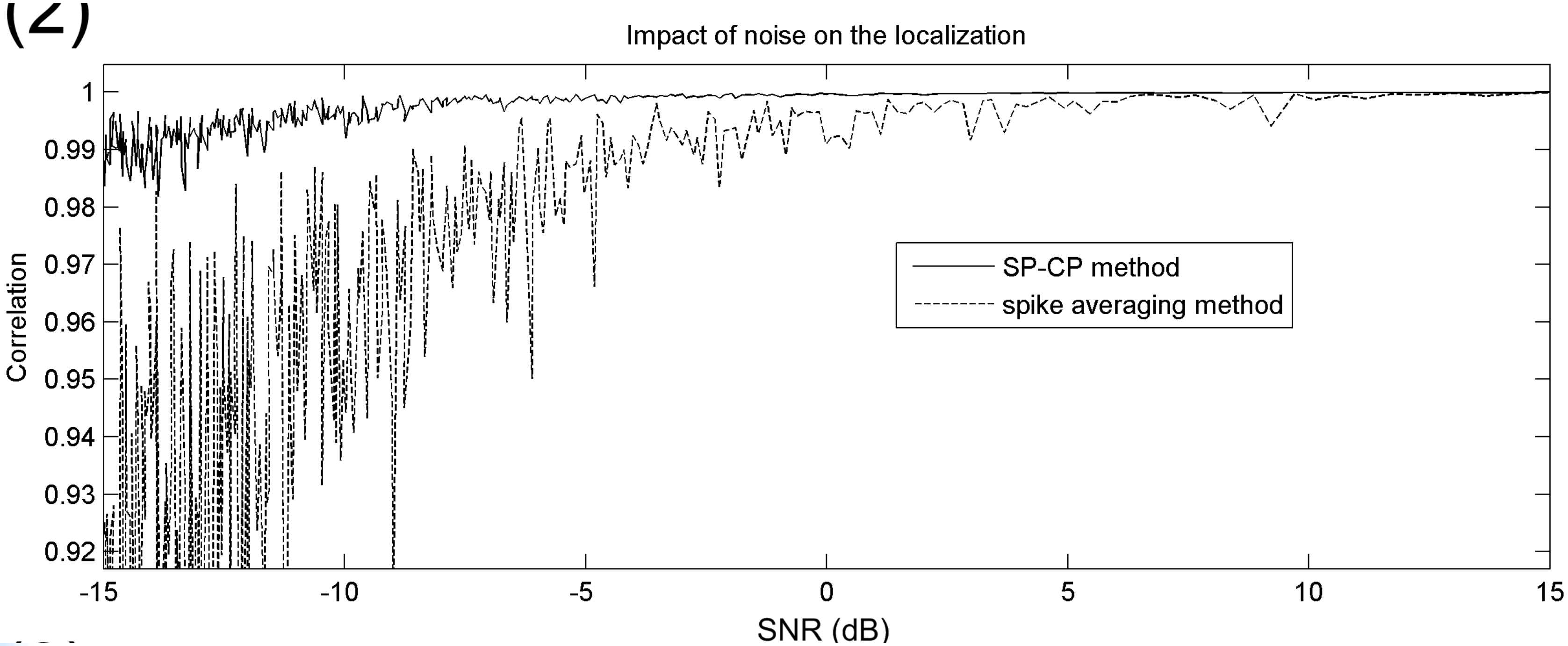


Fp1
F7
T3
=
C1
B1
A1
Distribution over the detected spikes
Contribution
Spike number
Amplitude
Time (s)
FP1
Fp2
F7
F8
T3
C3
Cz
C4
T4
T5
T6
O1
02

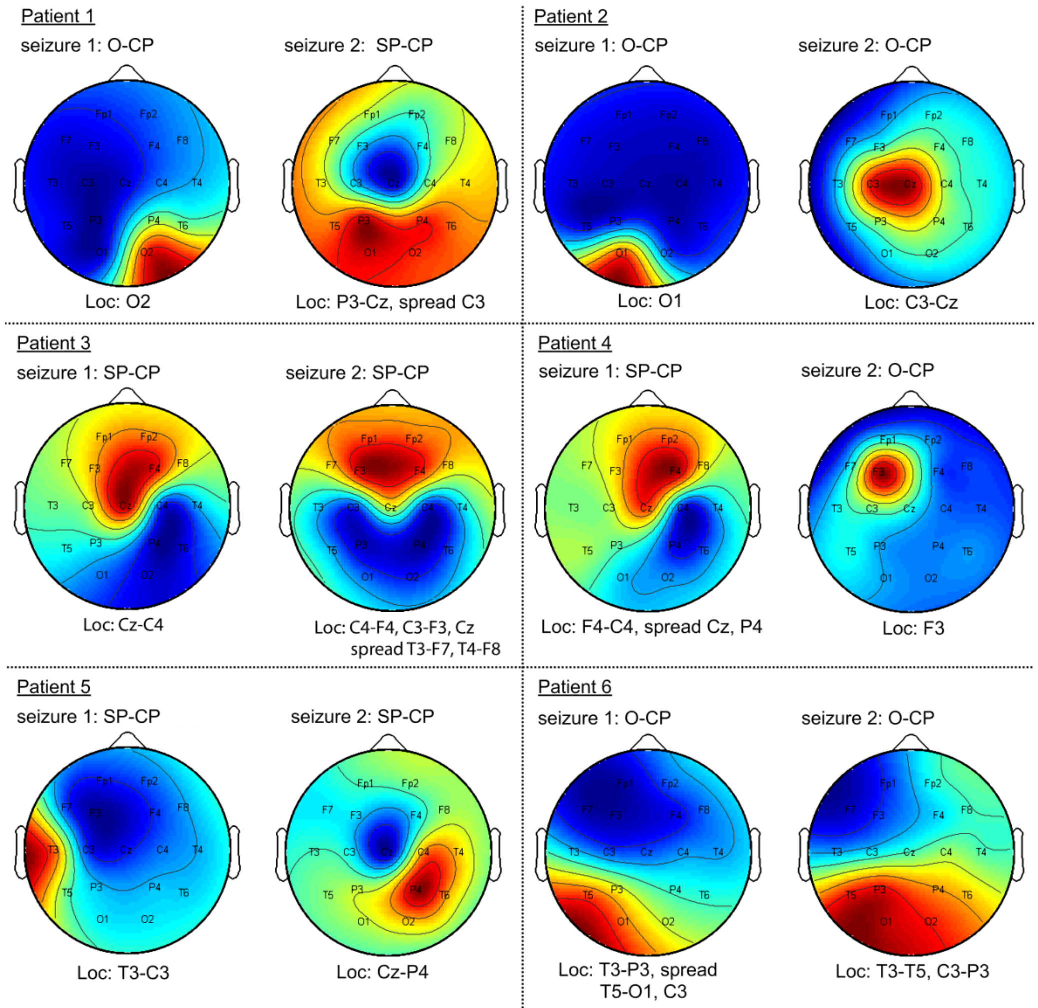
Comparison with spike averaging

- Construct tensor with 20 identical EEG spike segments
- Add random noise to the tensor with different SNR
- Calculate correlation with the noise free spatial distribution

(2)



Validation study



Comparison with visual analysis of the EEG by a neurophysiologist.

- In all cases there is a good qualitative correspondence between the neurologist and the algorithm.

- Localization plots are helpful tool for neurophysiologist in analyzing seizures.

- Together with seizure detector: useful for *brain monitoring at the bedside.*

Further remarks

PARAFAC expects a fixed localization in time:

→ Divide migrating seizures into smaller windows

Long seizures >1min:

→ Divide into smaller windows

Current research:

→ PARAFAC useful to delineate ictal onset zone?

1. use the extracted spatial distribution as *input to dipole source localization* with a realistic head model

2. *using simultaneous EEG-fMRI: prospective validation* in the presurgical work-up for epilepsy surgery.

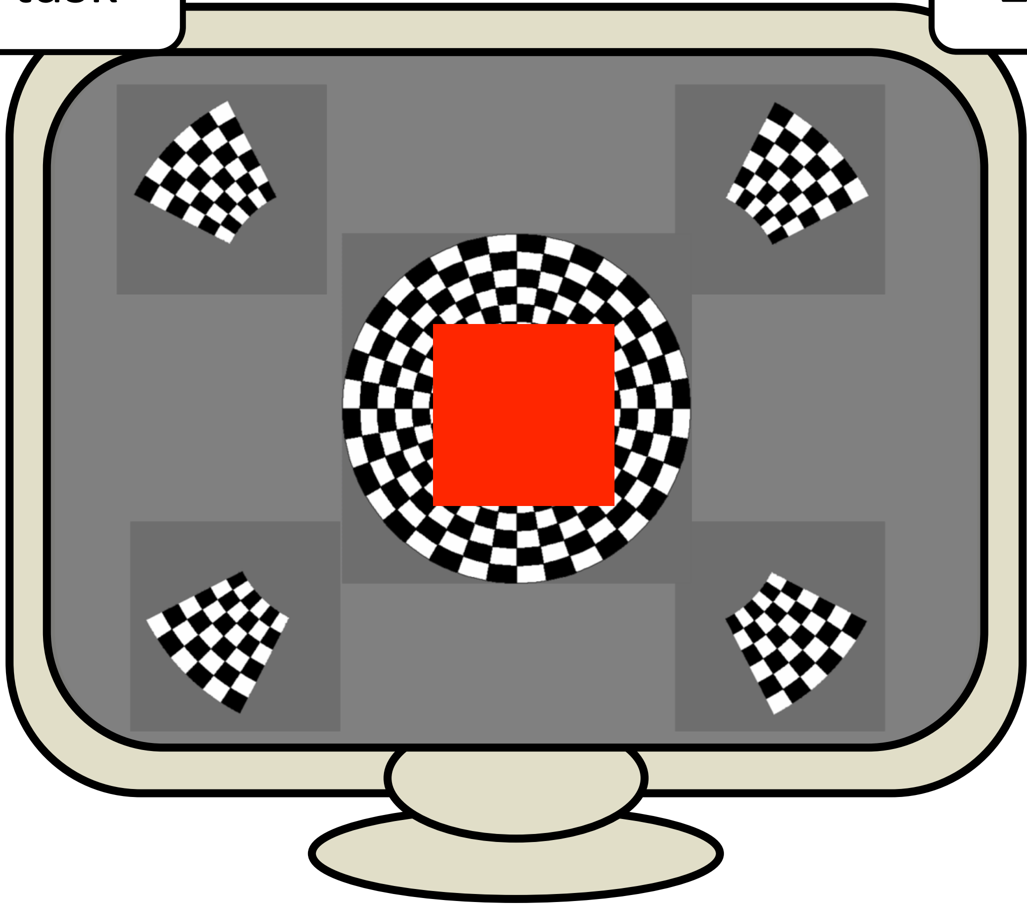
- Blind source separation
- Tensor Algorithms
- Examples in EEG monitoring
  - Epileptic seizure onset localization
  - Neonatal seizure localization
  - Event-Related Potential Analysis
- Conclusions and new directions

Tasks during data acquisition

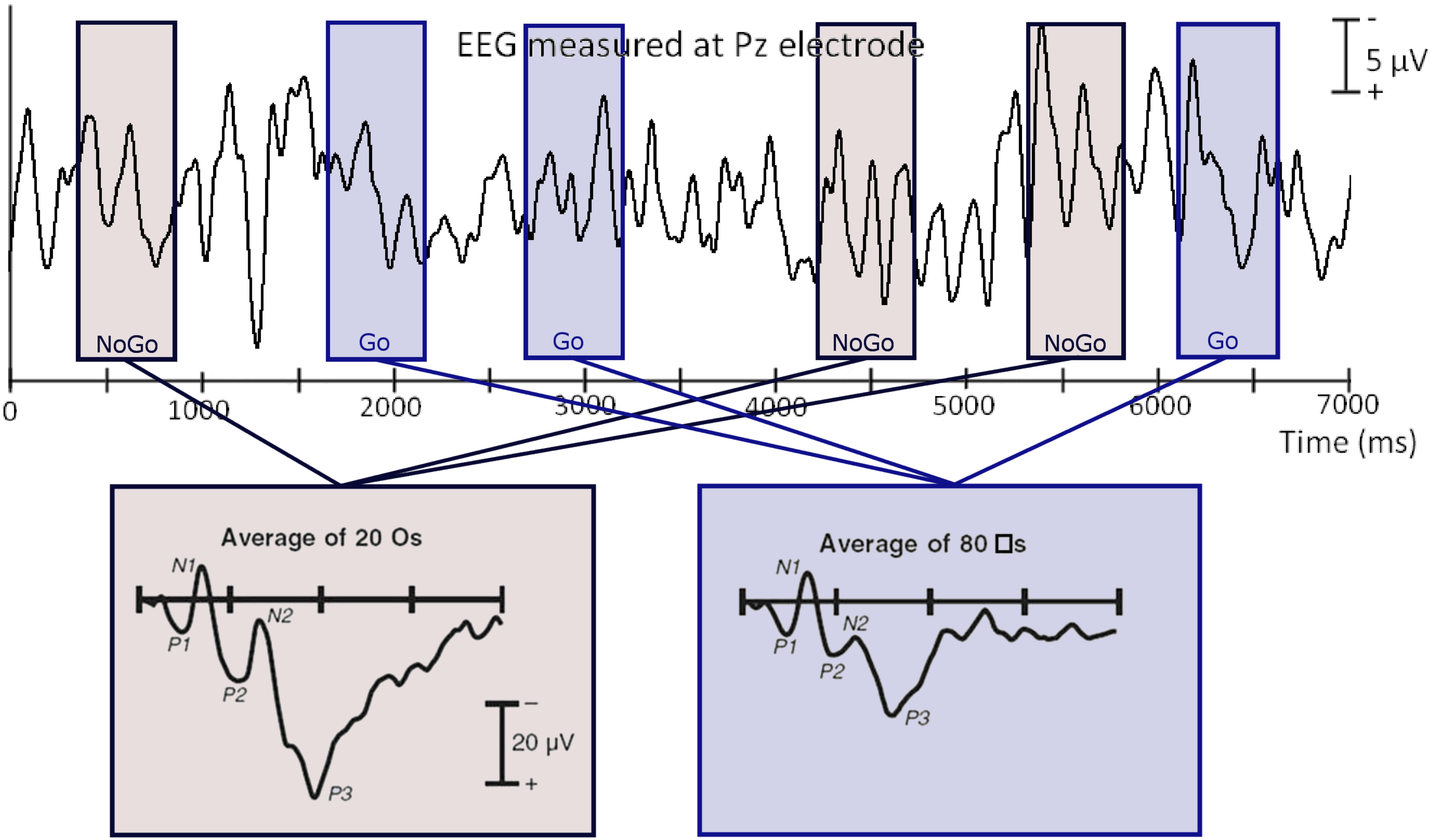
EEG with 62 electrodes+EOG+ECG in 3T
Variable randomized SOA

1. Detection task

2. Go/NoGo task



EEG analysis 1: average ERPs



ERPs have very low SNR and suffer from artifacts caused by non-brain and brain sources

Variety of PARAFAC Applications, e.g.:

-Brain topography *(Field and Graupe, Brain Topogr. 1991)*

-Brain-computer interfacing *(A. Cichocki, IEEE computer society magazine, 2008)*

- Detection of rhythmic activity, e.g. (α, θ), during cognitive task *(Miwakeichi et al., NeuroImage 2004) (Martinez-Montes, NeuroImage 2004) (Vanderperren et al., MBEC 2008)*

-Inter-trial phase coherence analysis in event-related EEG *(Mørup et al., NeuroImage 2005)(M. Weiss et al., ICASSP 2009)*

- Event-related EEG (during simultaneous fMRI acquisition)

ERP (outside or inside the scanner)

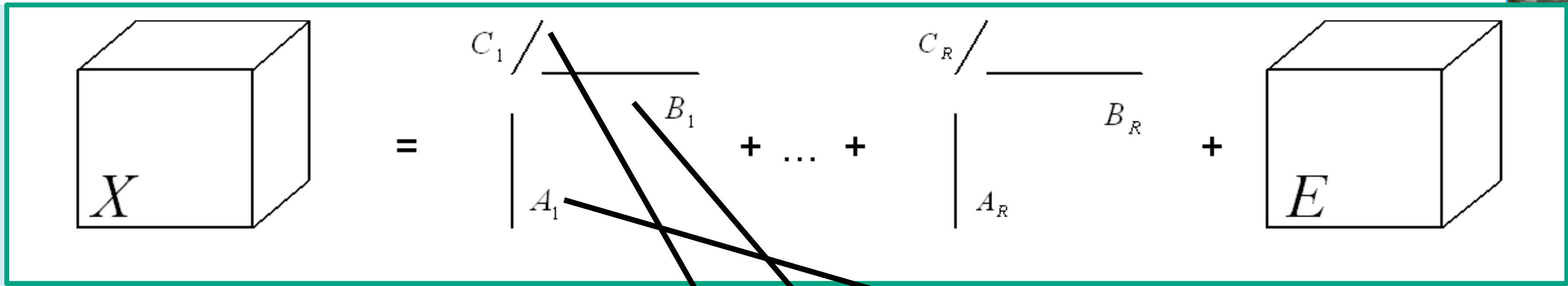
Application of PARAFAC to Event-Related EEG allows

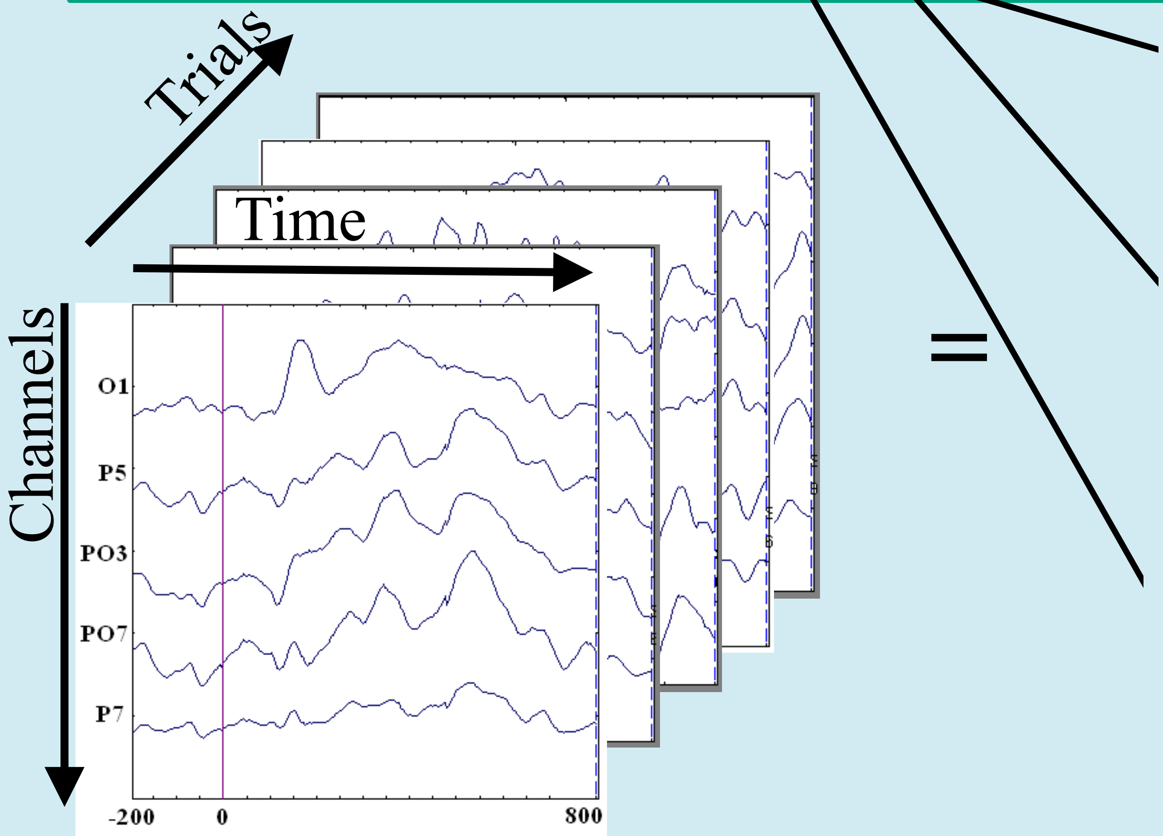
- including three or more data dimensions into the tensor for ERP analysis (e.g. subjects, trials, tasks, etc.)
- unique data decomposition without additional assumptions
- finding ERP properties not revealed by traditional averaging

Preprocessing important, e.g.

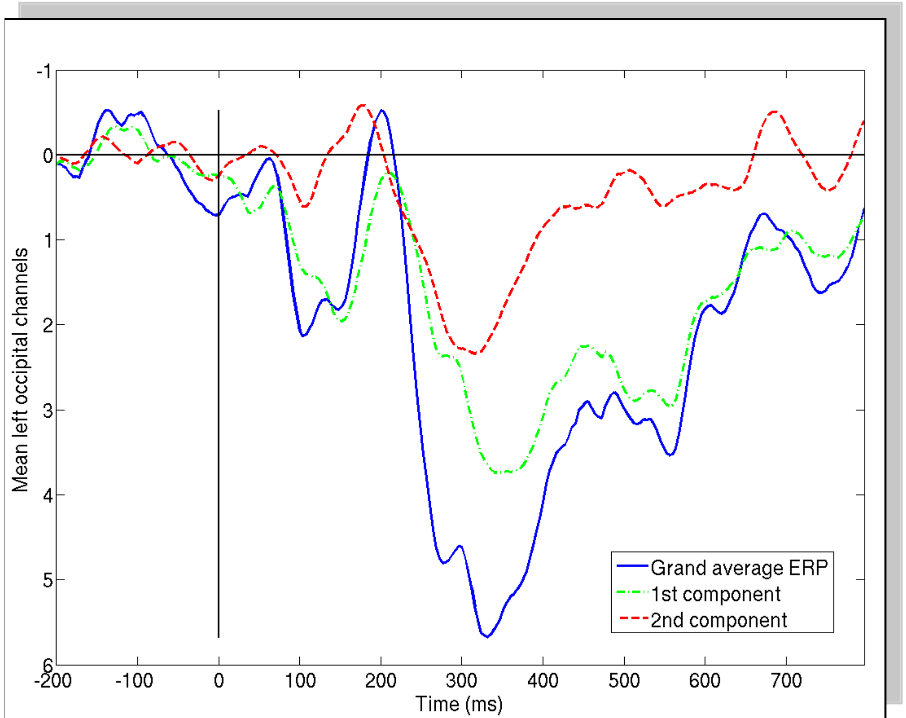
- removal of artifacts
- Imposing orthogonality in 1 mode (trial, subject) to avoid degeneracy
- Optimize parameters (number of components between 2 and 10)

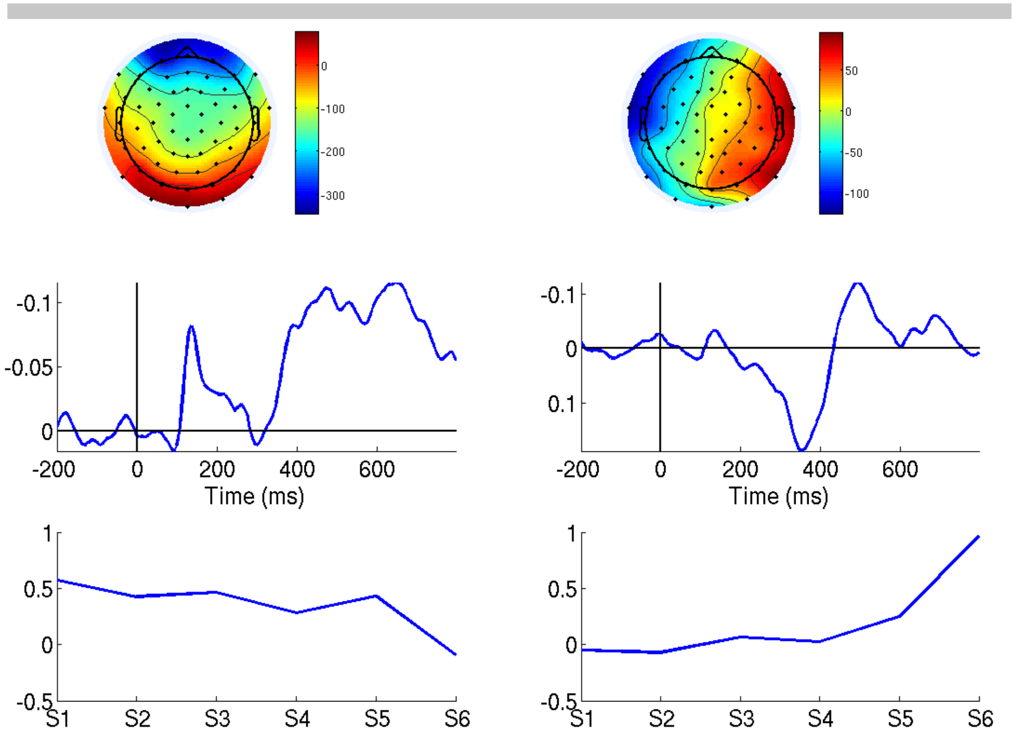
ERP analysis: PARAFAC on channels x time x trials





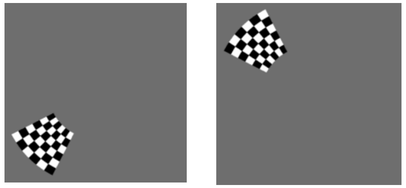
Recorded in scanner plus fMRI	Recorded in scanner, no fMRI
Averaged ERPs per subject	Averaged ERPs per subject
→ 5 left occipital channels	→ all channels
→ different P1 latencies found in grand average ERP separated in 2 components	*→2 components: grand average (left) and BCGartefact (right)*



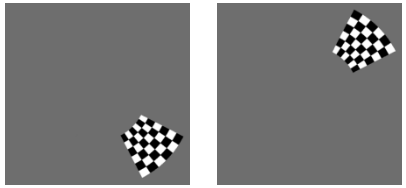


LEUVEN

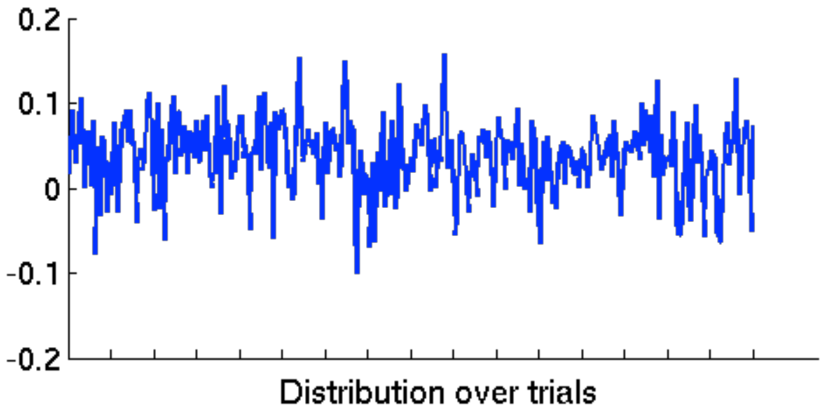
Validation: classification of trial type

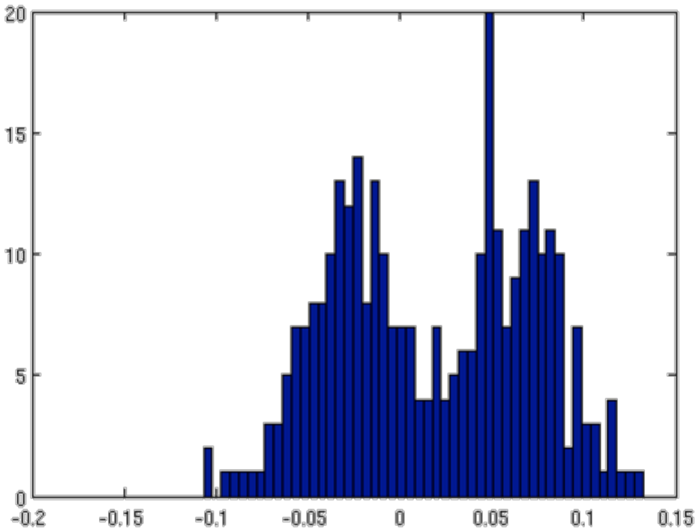


Left vs. right stimuli

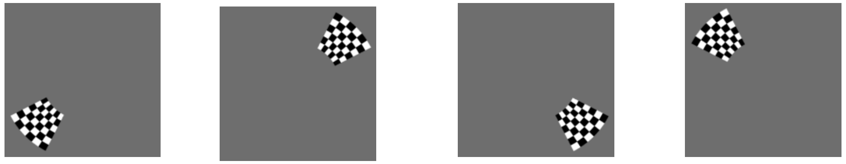


- Raw data: based on difference in P1 amplitude (left – right)
- PARAFAC: based on 1 trial mode of decomposition
- In both cases: ½ trials for training, ½ for testing

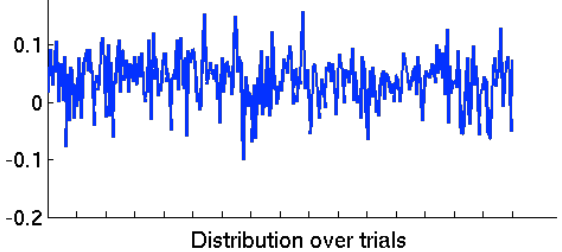


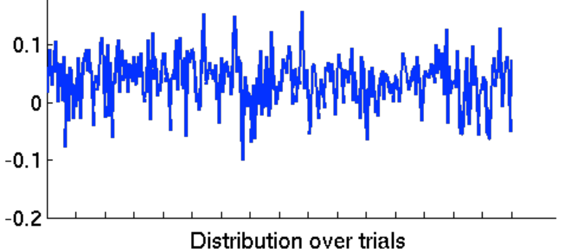


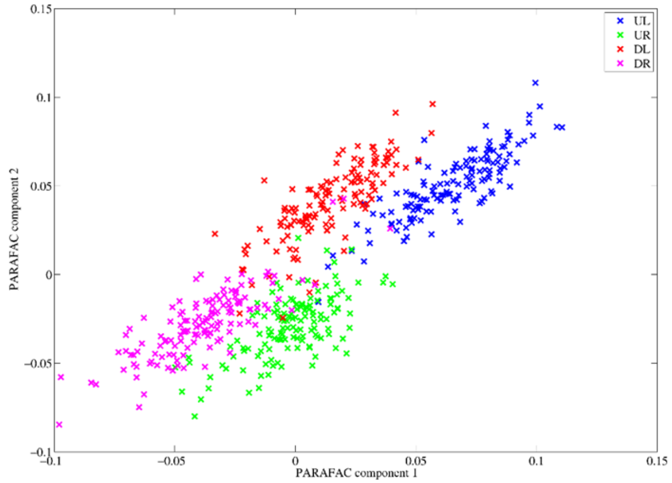
Quadrant stimuli



- Raw data: based on P1 left-right difference and C1 amplitude
- PARAFAC: based on 2 trial modes of decomposition
- In both cases: ½ trials for training, ½ for testing







Single trial ERP reading with PARAFAC

- PARAFAC allows the extraction of task-related ERP information on a single trial basis
- Performance is better than raw data characteristics
- Both for left-right and 4 quadrant distinction
- More difficult but still possible for simultaneously acquired EEG data

K. **Vanderperren**, B. Mijović, N. Novitskiy, B. Vanrumste, P. Stiers, B.R.H. Van den Bergh, L. Lagae, S. Sunaert, J. Wagemans, S. Van Huffel and M. De Vos. Single trial ERP reading based on Parallel Factor Analysis. Psychophysiology, 2012, to appear.

Contents Overview

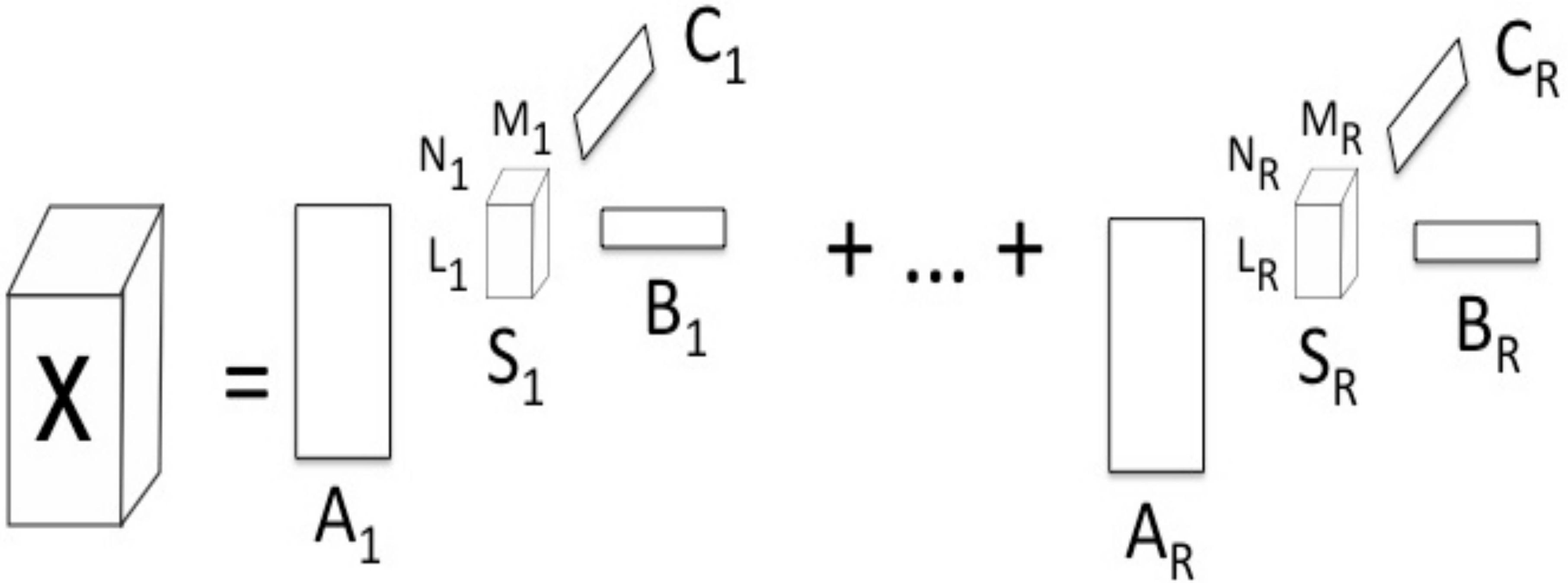
- Introduction
- Tensor Algorithms
- Examples in EEG monitoring
  - Epileptic seizure onset localization
  - Neonatal seizure localization
  - Event-Related Potential Analysis
- Conclusions and new directions

Conclusions: Tensors increasingly popular in biom. SP

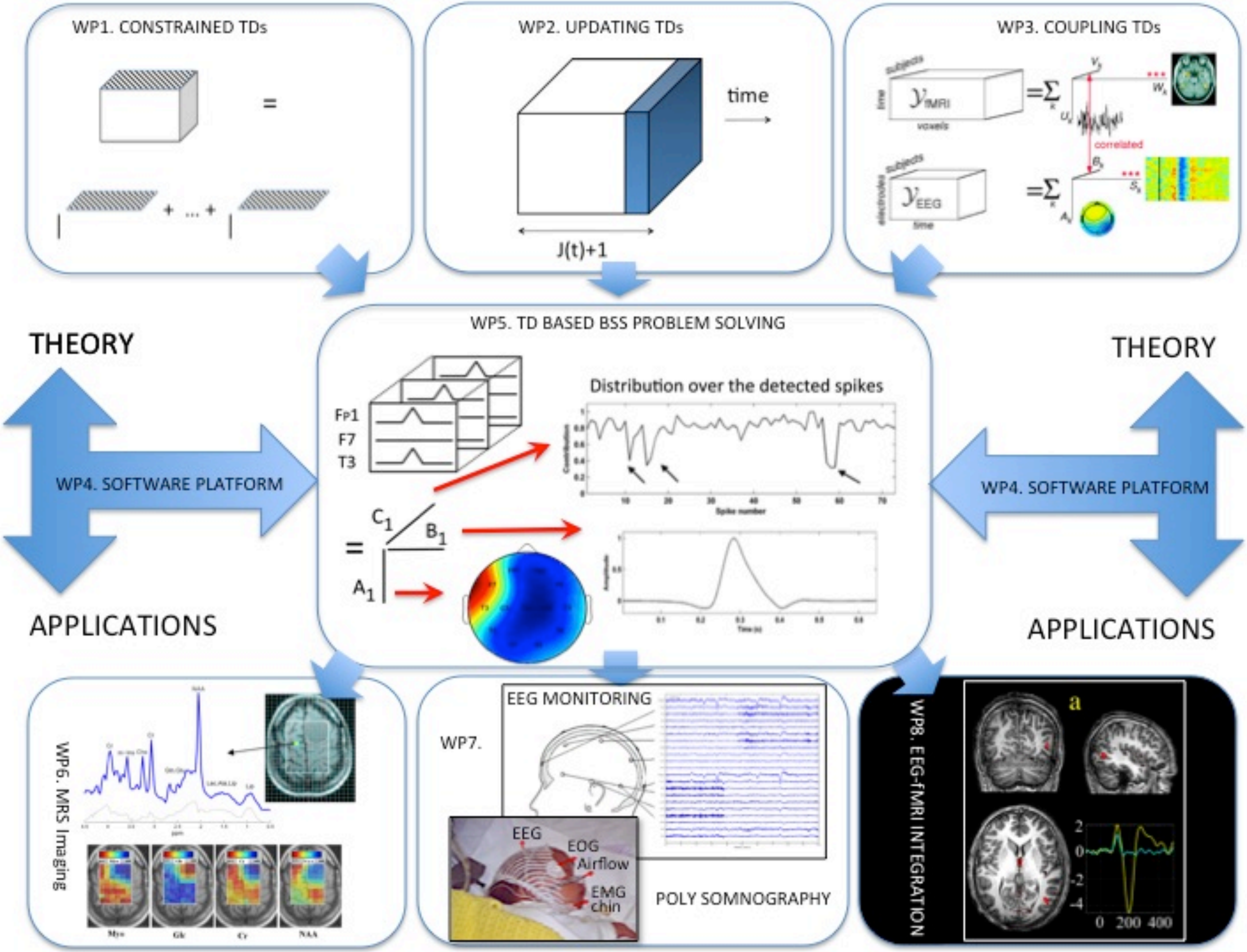
- Successful: e.g. epileptic seizure onset localization using multichannel EEG
- Mostly restricted to PARAFAC via alternating least squares
- PARAFAC more sensitive than visual EEG reading for seizure localization
- Electrode artifacts disturb localization …
- PARAFAC output used as starting point for 3D EEG source localization
- Remark: Tucker3 model has also been used for seizure localization *(Acar et al., IASTED 2007)*

Future challenges?

Block Tensor Decomposition

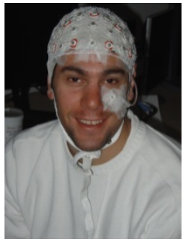


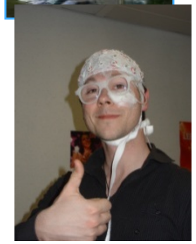
Ref: *De Lathauwer et al., SIMAX, 2008; Sorber et al., SIOPT, 2012*


WP1. CONSTRAINED TDs
WP2. UPDATING TDs
time
J(t)+1
WP3. COUPLING TDs
correlated
WP5. TD BASED BSS PROBLEM SOLVING
Distribution over the detected spikes
Fp1
F7
T3
THEORY
THEORY
WP4. SOFTWARE PLATFORM
WP4. SOFTWARE PLATFORM
APPLICATIONS
APPLICATIONS
WP6. MRS Imaging
WP7.
EEG MONITORING
EEG
EOG
Airflow
EMG
chin
POLY SOMNOGRAPHY
WP8. EEG-fMRI INTEGRATION

Acknowledgements

ESAT



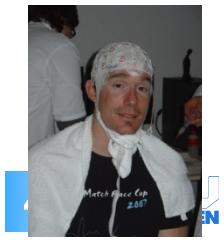


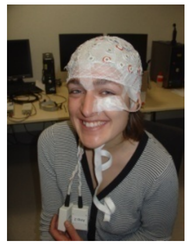
KATHOLIEKE UNIVERSITEIT LEUVEN O EEG-fMRI project

iWT

cost action NeuroMath

iMinds
CONNECT.INNOVATE.CREATE





Thank you for your attention!

Questions?

http://www.esat.kuleuven.be/scd/