Unsupervised Learning for Time-series: Extracting Patterns in Brain Recordings

Thomas Moreau – Parietal – Inria

Who am I?

Parcours

2014-2017: PhD – ENS Cachan (N. Vayatis & L. Oudre)

Applied Maths

Distributed optimization
Unsupervised learning
Representation learning

Healthcare Data

Gait analysis
Oculomotor recordings

2018-2019: Post-doc – Inria (Parietal)

Convolutional dictionary learning for MEG

$\Rightarrow$ **Local structure** analysis for signals

2019-∞: CR – Inria (Parietal)

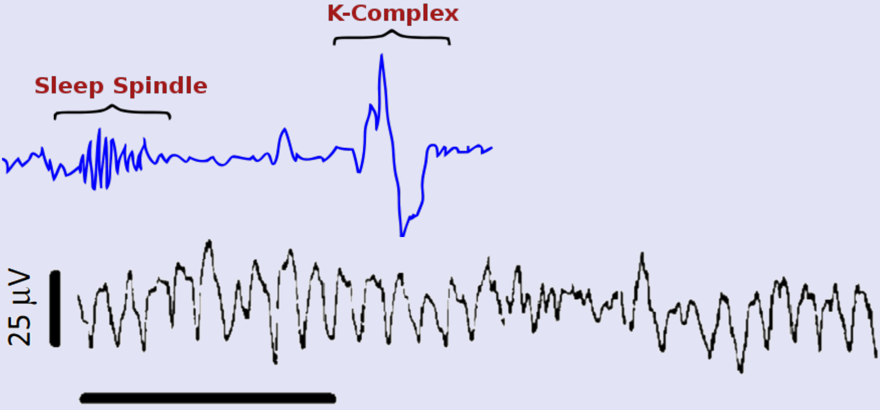
Unsupervised learning for brain signals

$\Rightarrow$ Finding structure in brain recordings!

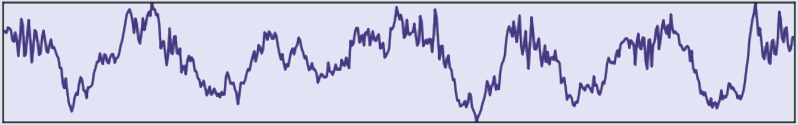
Unsupervised Learning for Electrophysiology
Convolutional Dictionary Model

References

- Dupré la Tour, T., Moreau, T., Jas, M., and Gramfort, A. (2018). Multivariate Convolutional Sparse Coding for Electromagnetic Brain Signals. In *Advances in Neural Information Processing Systems (NeurIPS)*, pages 3296–3306, Montreal, Canada
- Moreau, T., Oudre, L., and Vayatis, N. (2018). DICOD: Distributed Convolutional Sparse Coding. In *International Conference on Machine Learning (ICML)*, pages 3626–3634, Stockohlm, Sweden. PMLR (80)



[S. Cole, B. Voytek (2017) Trends in Cognitive Sciences]



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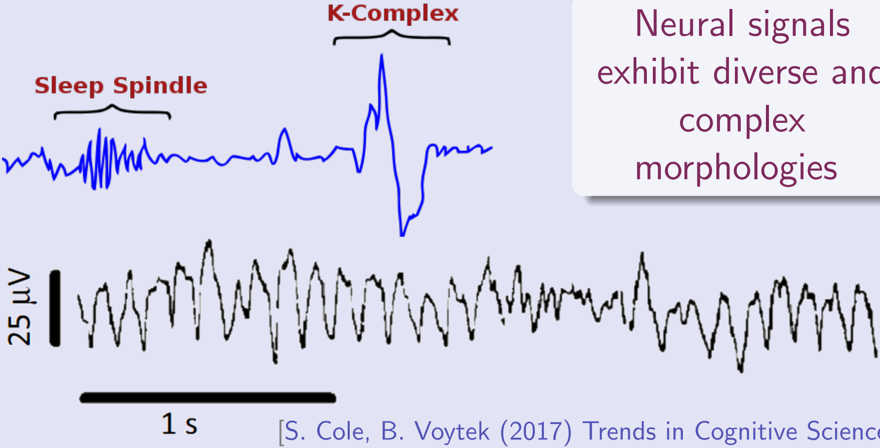
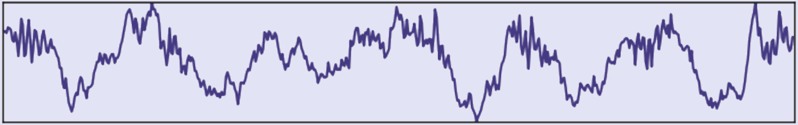


Neural signals exhibit diverse and complex morphologies

[S. Cole, B. Voytek (2017) Trends in Cognitive Sciences]



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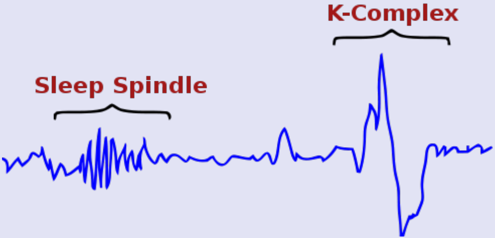

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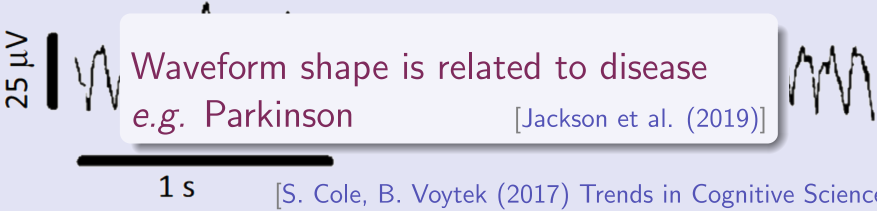
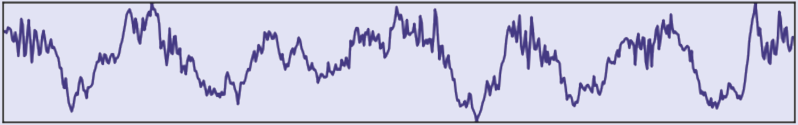


Waveform shape is related to disease

e.g. Parkinson [Jackson et al. (2019)]

[S. Cole, B. Voytek (2017) Trends in Cognitive Sciences]



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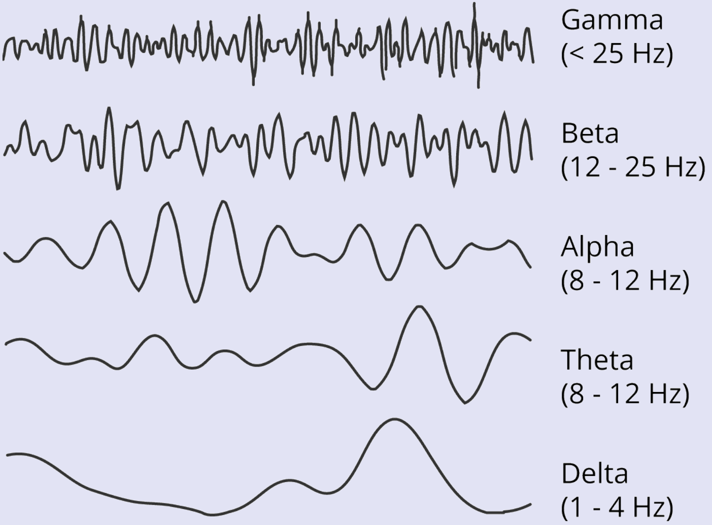
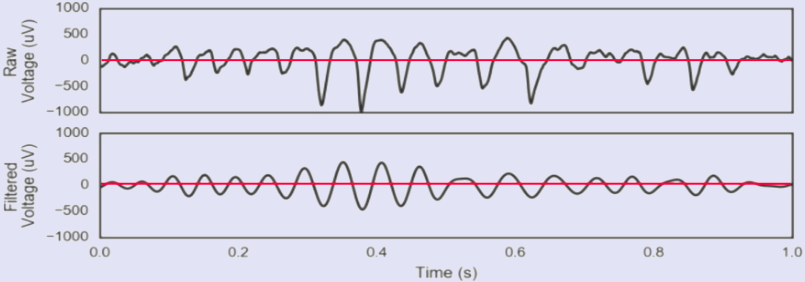
"Textbook" brain rythm [According to Alex!]



Linear filtering

After Linear filters, everything looks like a sinusoïd.



$\Rightarrow$ Lose the asymmetry and the shape information.

Fourier Fallacy

"Even though it may be possible to analyze the complex forms of brain waves into a **number of different sine-wave** frequencies, this may lead only to what might be termed a "**Fourier fallacy**", if one assumes **ad hoc** that all of the necessary frequencies actually occur as periodic phenomena in **cell groups** within the brain."

[Jasper (1948)]

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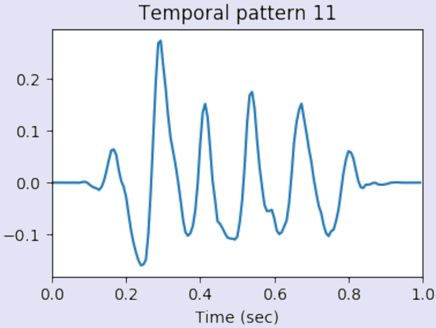

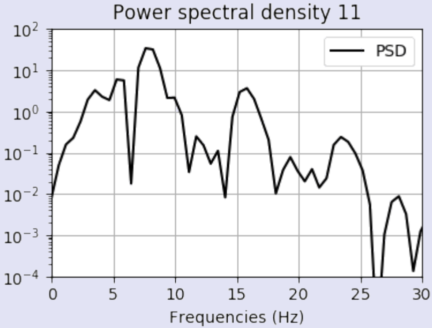

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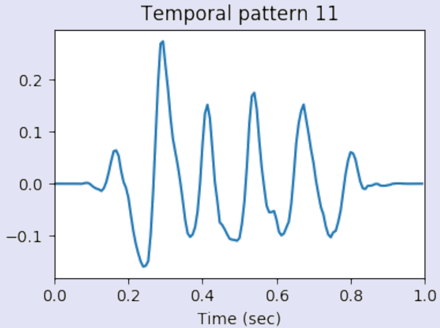
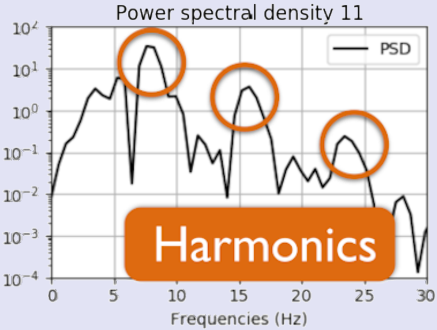
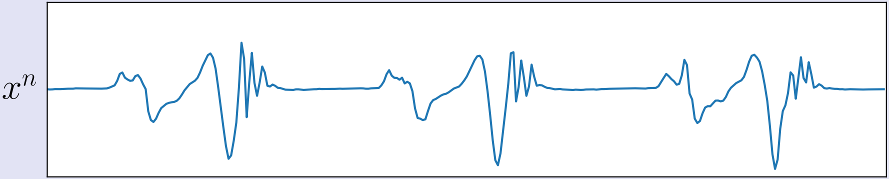




Can't we learn the waveforms?

Local structure in signals



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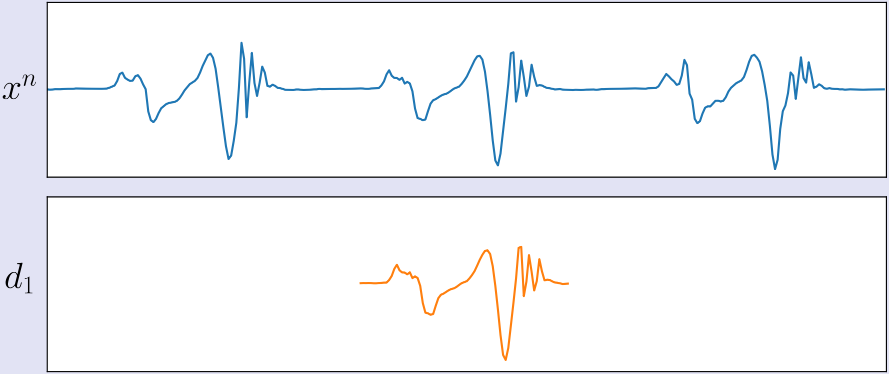

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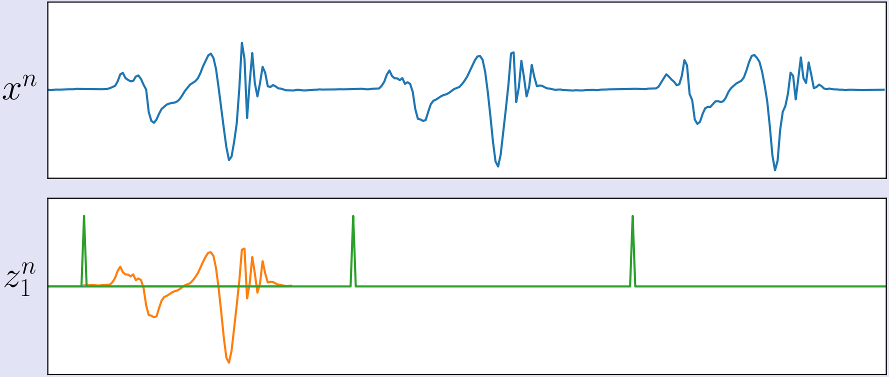

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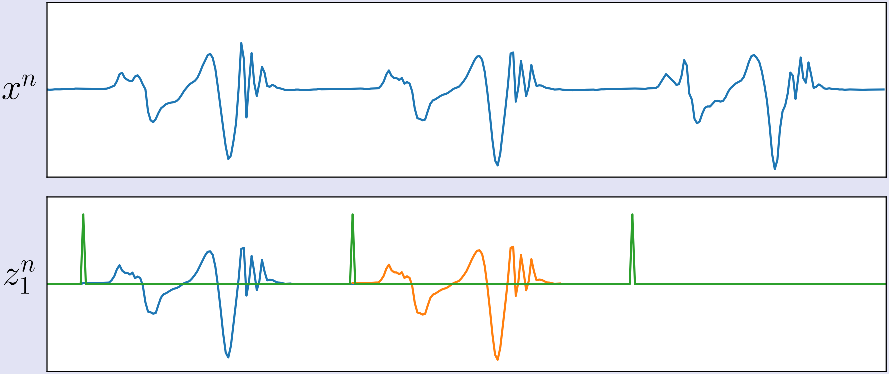

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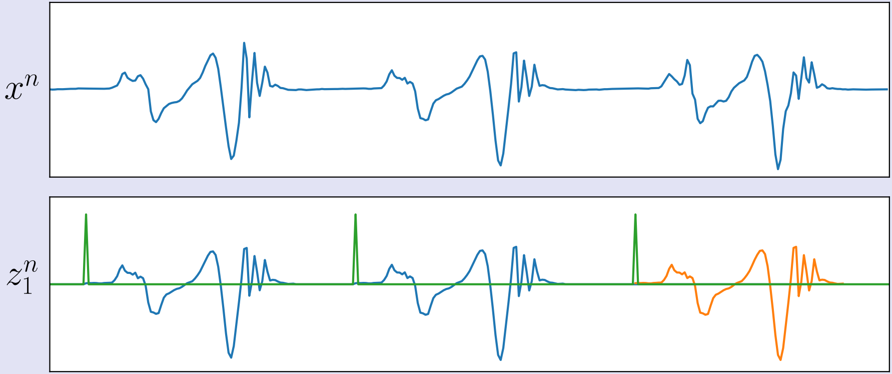

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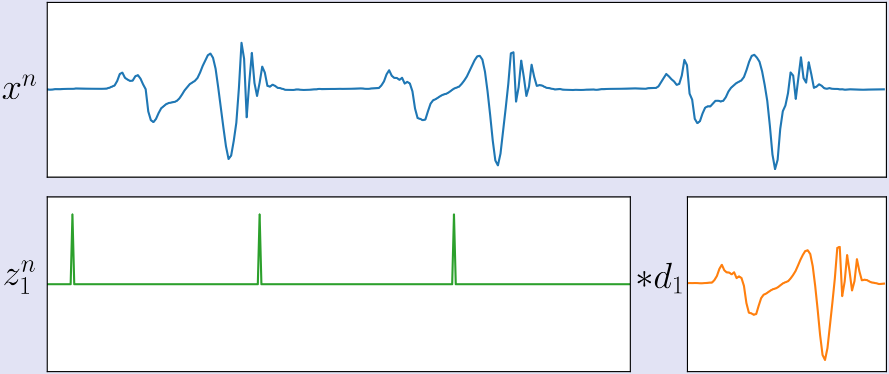

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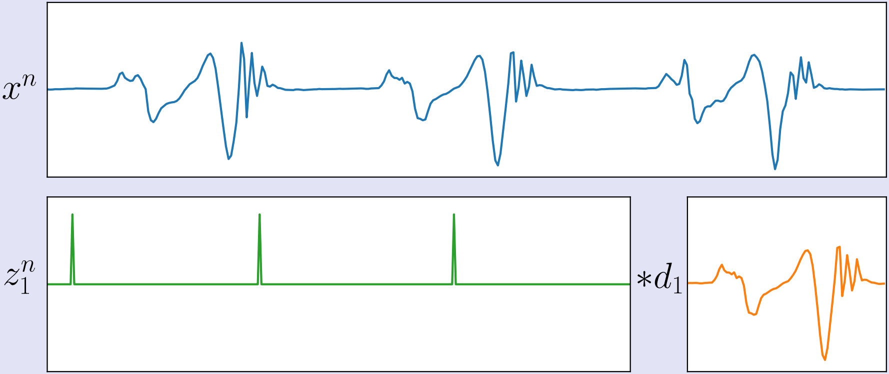
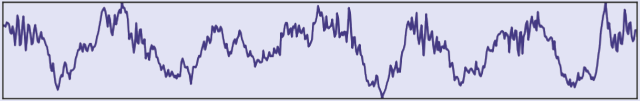
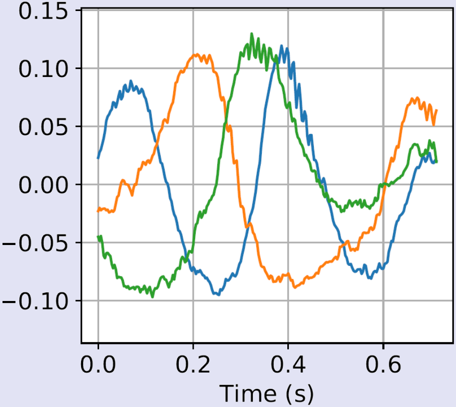


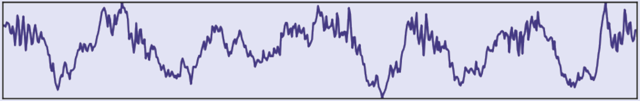
$$\boxed{x^n}[t] = \sum_{k=1}^{K} (\boxed{z_k^n} * \boxed{d_k})[t] + \varepsilon[t]$$

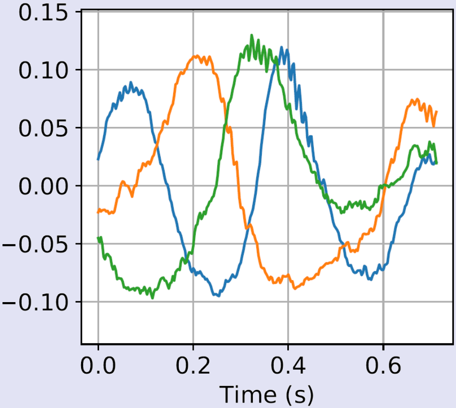
Data:





Data:

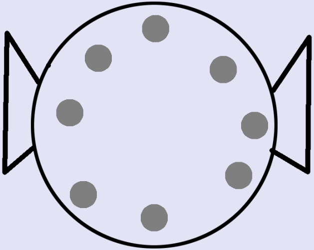




What to do in the case of multivariate signals?

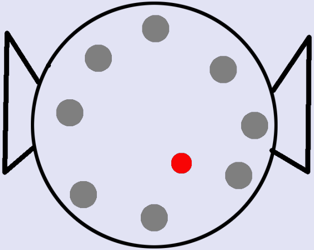
EM wave diffusion

- Recording here with 8 sensors



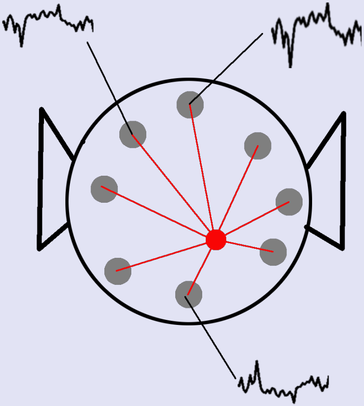
EM wave diffusion

- Recording here with 8 sensors
- EM activity in the brain



EM wave diffusion

- Recording here with 8 sensors
- EM activity in the brain
- The electric field is spread **linearly** and **instantaneously** over all sensors (Maxwell equations)



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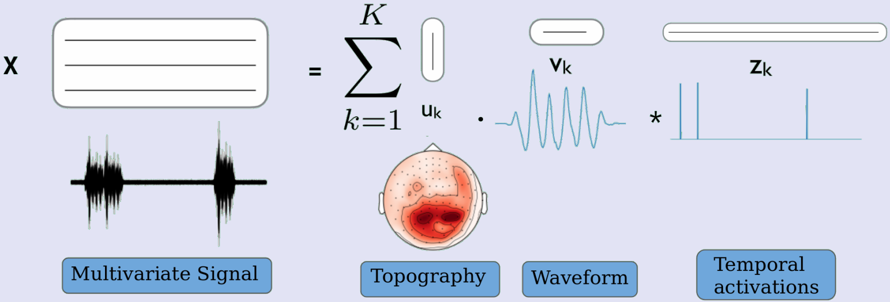
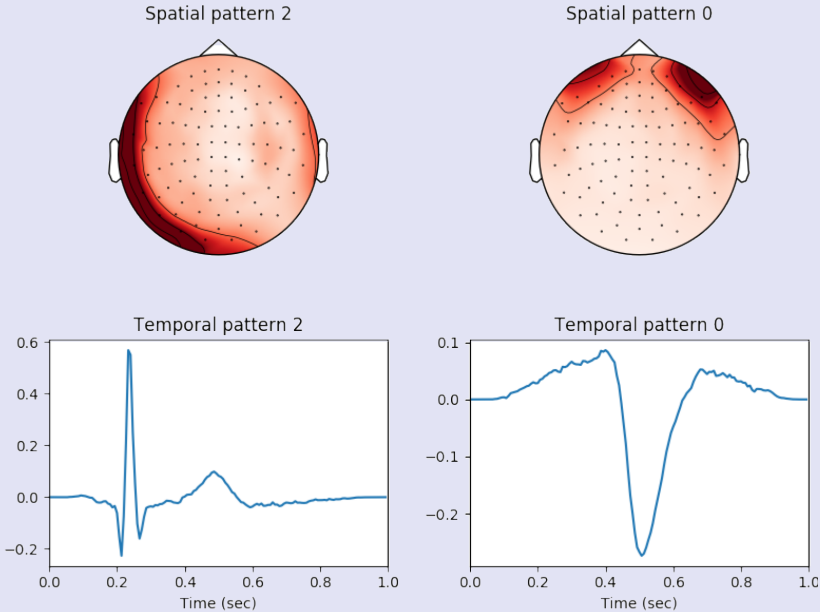
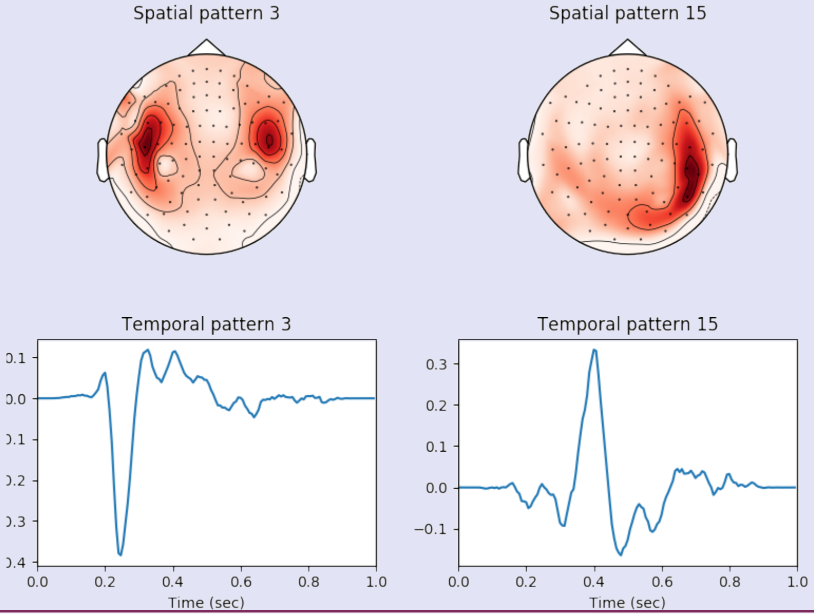


Learned atoms – Artifacts



Learned atoms – Evoked response



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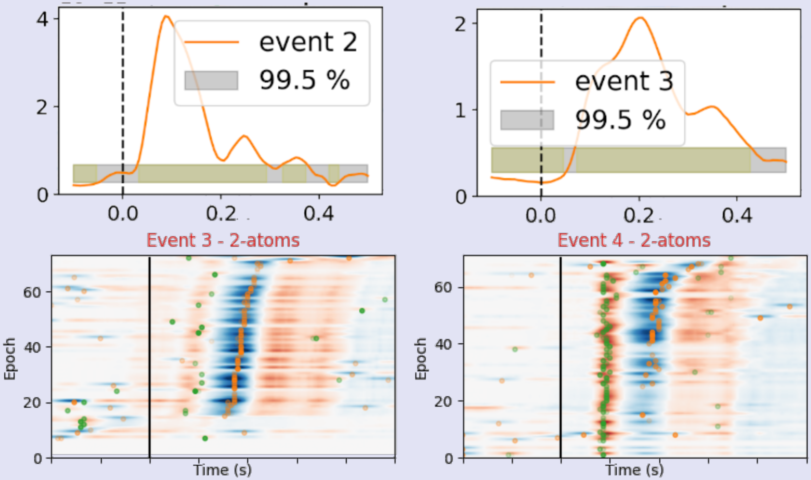
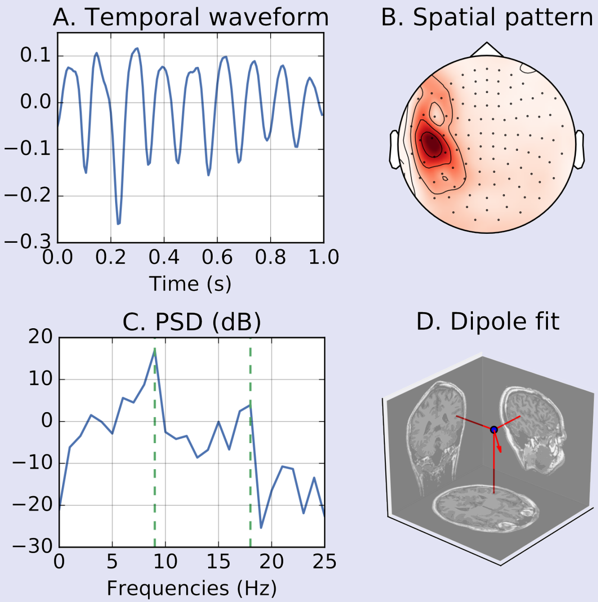


Learned atoms – Evoked response

Work in progress!

Learned atoms – Complex waveforms



alphaCSC: Convolution sparse coding for time-series

build passing codecov 82%

This is a library to perform shift-invariant sparse dictionary learning, also known as convolutional sparse coding (CSC), on time-series data. It includes a number of different models:

1. univariate CSC
2. multivariate CSC
3. multivariate CSC with a rank-1 constraint [1]
4. univariate CSC with an alpha-stable distribution [2]

A mathematical descriptions of these models is available in the documentation.

Installation

To install this package, the easiest way is using `pip`. It will install this package and its dependencies. The `setup.py` depends on `numpy` and `cython` for the installation so it is advised to install them beforehand. To install this package, please run one of the two commands:

(Latest stable version)

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pip install numpy cython
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alphacsc 0.3 Models Examples API GitHub Site Search

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Examples reproduce figures from this talk!

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Convolutional Dictionary Learning

- Flexible pattern extraction technique,
- Computationally tractable for more and more problems,
- Some application are already beginning to emerge.

Challenges

- Theoretical challenges remains (convergence, recoverability),
- The evaluation (and thus the parameter choices) is still not clear,
- Can give some insight for deep learning models?

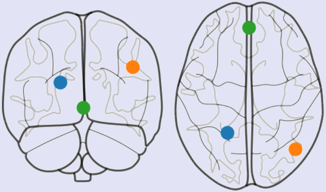
How to highlight temporal dependency?

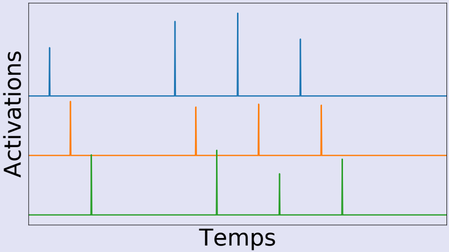
Model inter-atom interactions:

Pénalité ℓ_1

$\Rightarrow$ independent activations

Independent activations





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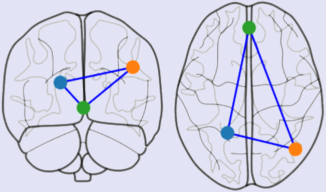
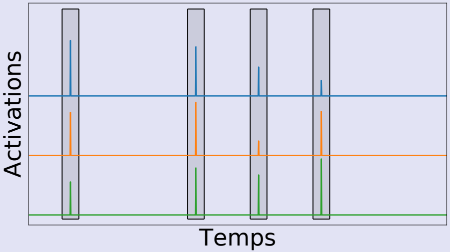
Group penalty (*e.g.* $\ell_{1,2}$)

$\Rightarrow$ simultaneous activations

Simultaneous activations





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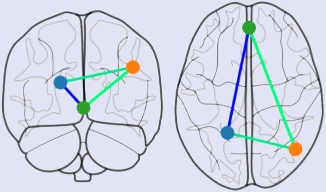
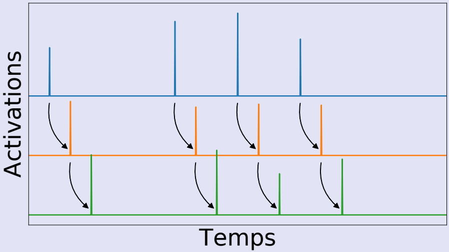
Point process ponctuels (*e.g.* Hawkes)

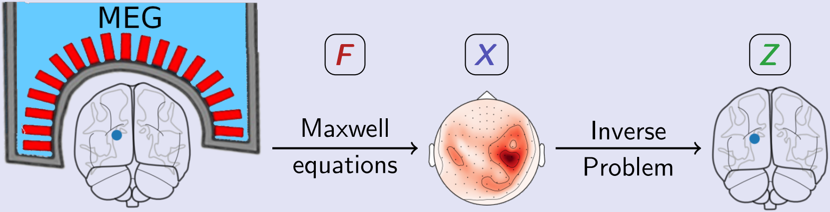
$\Rightarrow$ temporal interactions

Temporal interactions





Deep Learning for Inverse problem



Inverse Problem: $\operatorname{argmin}_Z \|X - FZ\|_2^2 + \mathcal{R}(Z)$

- Fast iterative solvers to compute Z [Massias et al. (2017)]
- Use of deep learning to inverse this system [Moreau et al. (2017); Ablin et al. (2019)]

Thanks!

Code available online:

alphacsc : alphacsc.github.io

Slides are on my web page:

tommoral.github.io @tomamoral