DE LA RECHERCHE À L'INDUSTRIE

SPARSITY-BASED BLIND DECONVOLUTION OF NEURAL ACTIVATION SIGNAL IN FMRI

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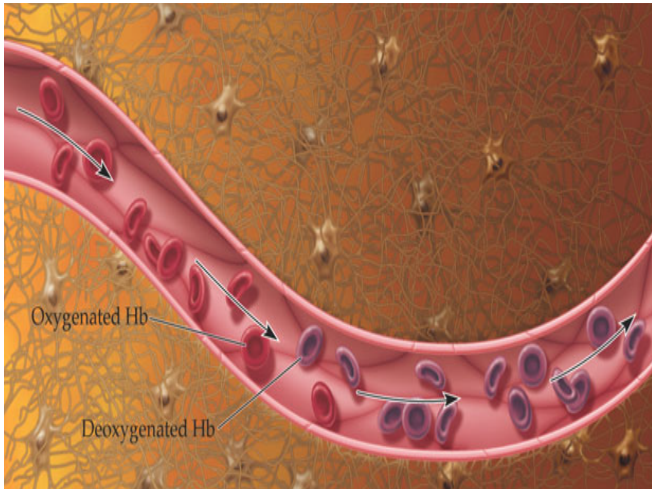
ORIGIN OF THE 'BLOOD OXYGENATION LEVEL DEPENDENT' SIGNAL

Neurovascular coupling:

Brain activation → Slight increase of O_2 consumption accompanied by **strong inflow of oxygenated blood** [Ogawa et al, 1990,1992]



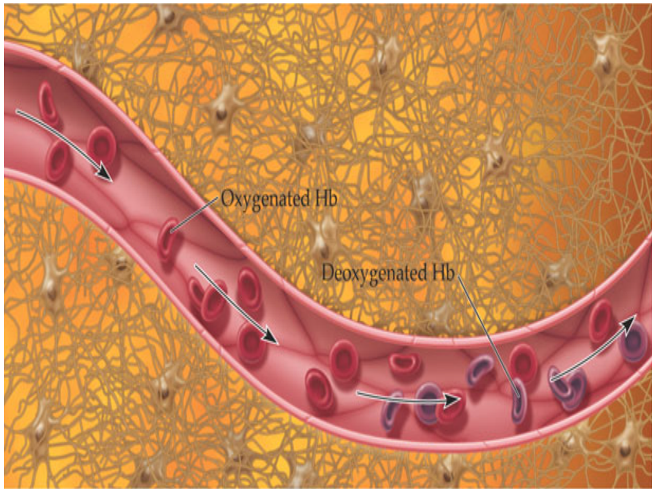
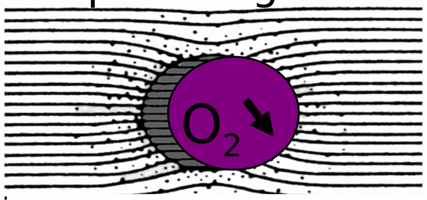


Figure Source, Huettel, Song & McCarthy, *2004, Functional Magnetic Resonance Imaging*

De-oxyhemoglobin (Hb): paramagnetic

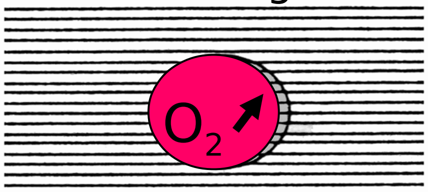


«baseline »

↓

Signal decrease

Oxyhemoglobin (HbO2): diamagnetic



Brain activation

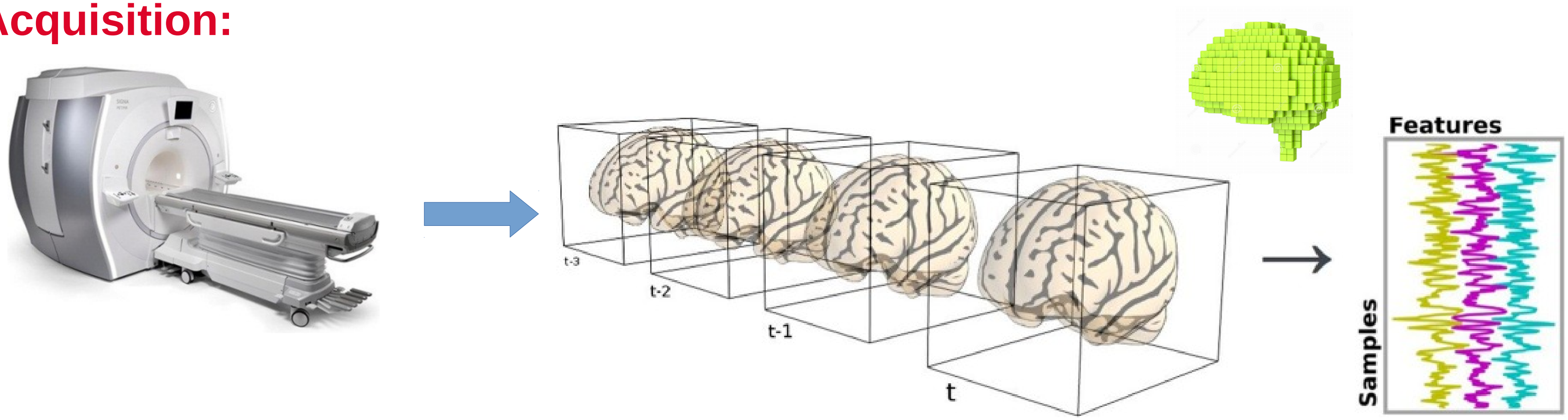
↓

Signal increase

→ Modification of the T_2^* of the brain tissue

FUNCTIONAL MAGNETIC RESONANCE IMAGING DATA

Acquisition:



Blood oxygenation level dependent: **BOLD** → **INDIRECT OBSERVATION OF THE NEURAL ACTIVITY**

Preprocessing: Realignement, slice timing, coregistration, normalization to a brain template, smoothing, (detrending), (filtering)

Notation:

$$Y = [y_1, .., y_v] \in \mathbb{R}^{n \times v}$$

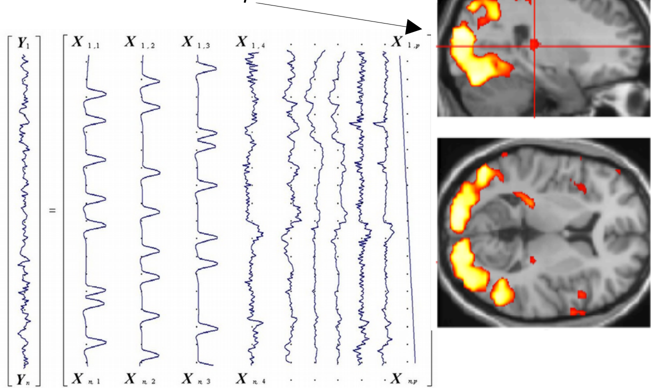
v the number of voxels (ex **230,314 voxels** for HCP)
n the number of time frames (ex **284 time frames** for HCP)

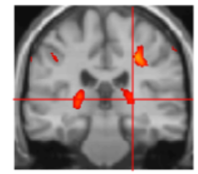
CLASSICAL ANALYSIS PIPELINE

Task fMRI:

Task fMRI: stimuli delivered at specifc time points, e.g. watching a movie, listening to music, voice, etc

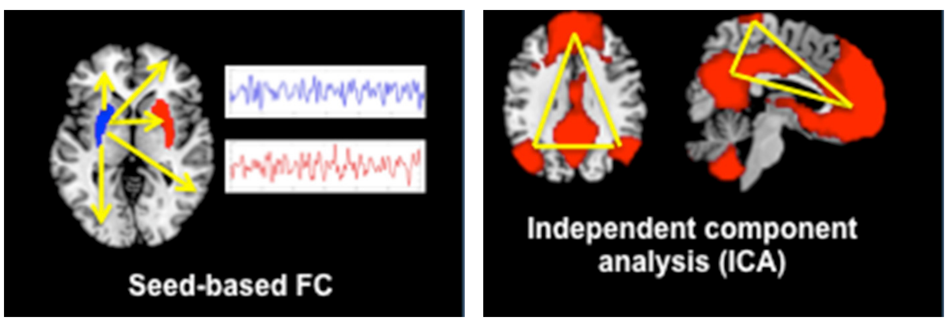
$$Y = X\beta + E$$





Characterize the correlation between predefined regressors: via a linear model

Resting-state fMRI:



Characterize the interaction between BOLD time series: correlation, independence, etc

Resting-state fMRI: subject at rest.

What to remember about classical analysis pipeline:

based on **BOLD time series** → **INDIRECT OBSERVATION OF THE NEURAL ACTIVITY**

QUESTION

Can fMRI analysis rely on a neural activation signal?

The model...

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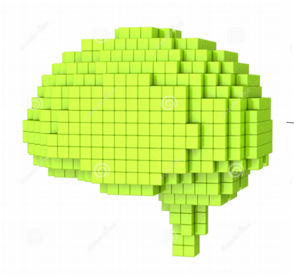
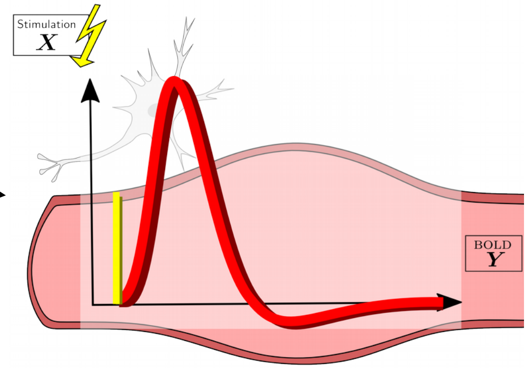


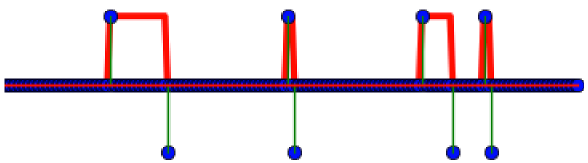
What happens in a voxel ?



Heamodynamic Response Function (**HRF**)

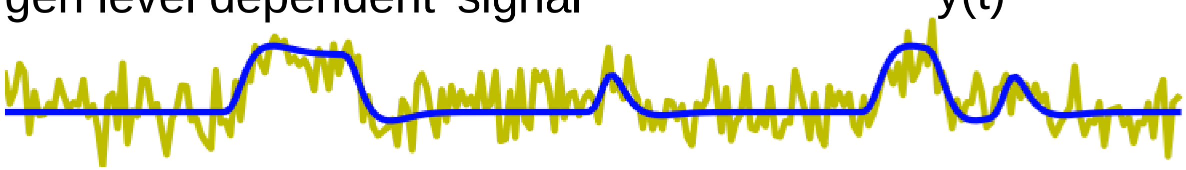
$$y(t) = h(t) \star Lz(t) + \epsilon(t)$$

1 ‘neural activation signal’



2 ‘oxygen level dependent’ signal

y(t)



DEFINITION OF THE BLIND DECONVOLUTION ESTIMATOR

Main cost-function:

- **Cost function:**

$$J(z,\theta) = \frac{1}{2}\left\|h_\theta * Lz - y\right\|_2^2 + \lambda \left\|z\right\|_1 + I_{\{\theta \in Q\}}$$

with $h_\theta(t)$ a parametric HRF model here we choose $h_\theta(t) = h_{ref}(\theta t)$ (time dilation)

- **Split into two sub cost functions :**

$$J_\theta(z) = \frac{1}{2}\left\|h_\theta * Lz - y\right\|_2^2 + \lambda \left\|z\right\|_1$$

$$J_z(\theta) = \frac{1}{2}\left\|h_\theta * Lz - y\right\|_2^2 + I_{\{\theta \in Q\}}$$

Optimization method:

- Alternated optimization of J_x and J_θ

- J is not globally convex (notably due to the convolution)
- J_θ is convex
- J_z 's convexity depends on the HRF model

OPTIMIZATION

Main loop:

Algorithm 1: Blind deconvolution scheme of the BOLD signal.

Input: BOLD signal $\boldsymbol{y}$, stopping rule ν

1 initialization: $\alpha^{(0)}$, $\boldsymbol{u}^{(0)} = 0$, $k = 1$;

2 **repeat**

3 Deconvolution of the BOLD signal for $\boldsymbol{h}_{\alpha^{(k-1)}}$:

$$\boldsymbol{u}^{(k)} = \operatorname*{argmin}_{\boldsymbol{u}\in\mathbb{R}^n} \frac{1}{2} \|\boldsymbol{h}_{\alpha^{(k-1)}} \star \boldsymbol{L}\boldsymbol{u} - \boldsymbol{y}\|_2^2 + \lambda\|\boldsymbol{u}\|_1$$

4 Estimate the HRF parameter with fixed $\boldsymbol{u}^{(k)}$:

$$\alpha^{(k)} = \operatorname*{argmin}_{\alpha\in\mathbb{R}} \frac{1}{2} \left\|\boldsymbol{h}_{\alpha} \star \boldsymbol{L}\boldsymbol{u}^{(k)} - \boldsymbol{y}\right\|_2^2$$

subject to $\alpha_{\min} \leqslant \alpha \leqslant \alpha_{\max}$

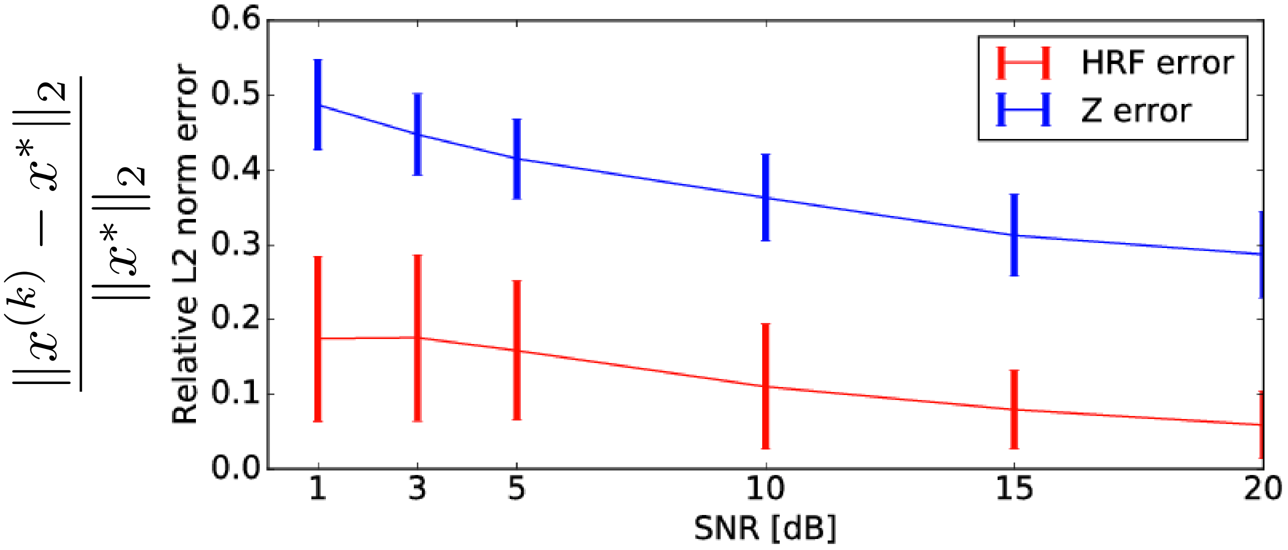
5 **until** $\|\alpha^{(k)} - \alpha^{(k-1)}\|_2 / \|\alpha^{(k)}\|_2 < \nu$;

VALIDATION ON SYNTHETIC FMRI DATA

Results:

Parameters of the experiment:

- generating 100 synthetic BOLD time series (i.e. 100 **voxels**)
- SNR=[1.0, 3.0, 5.0, 10.0, 15.0, 20.0] dB, TR=0.75s, duration of 3min (n=240 scans)
- 5 blocks of an average duration of 12s
- A single unknown HRF over all voxels
- regularization parameters: cross-validated with the ground truth

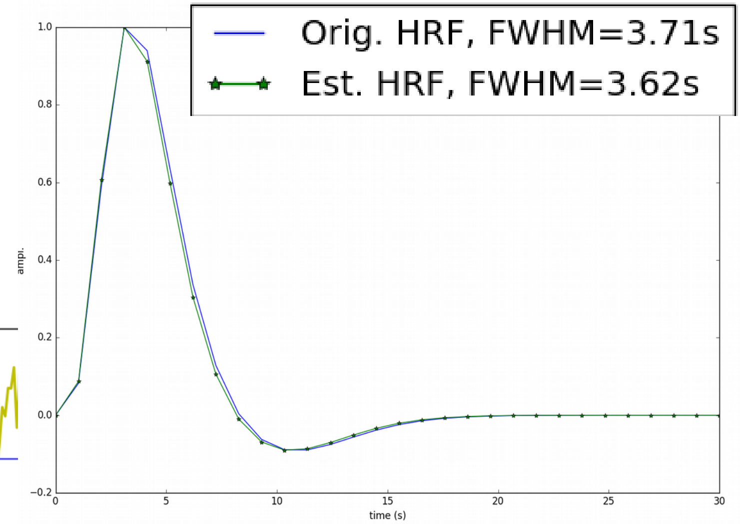


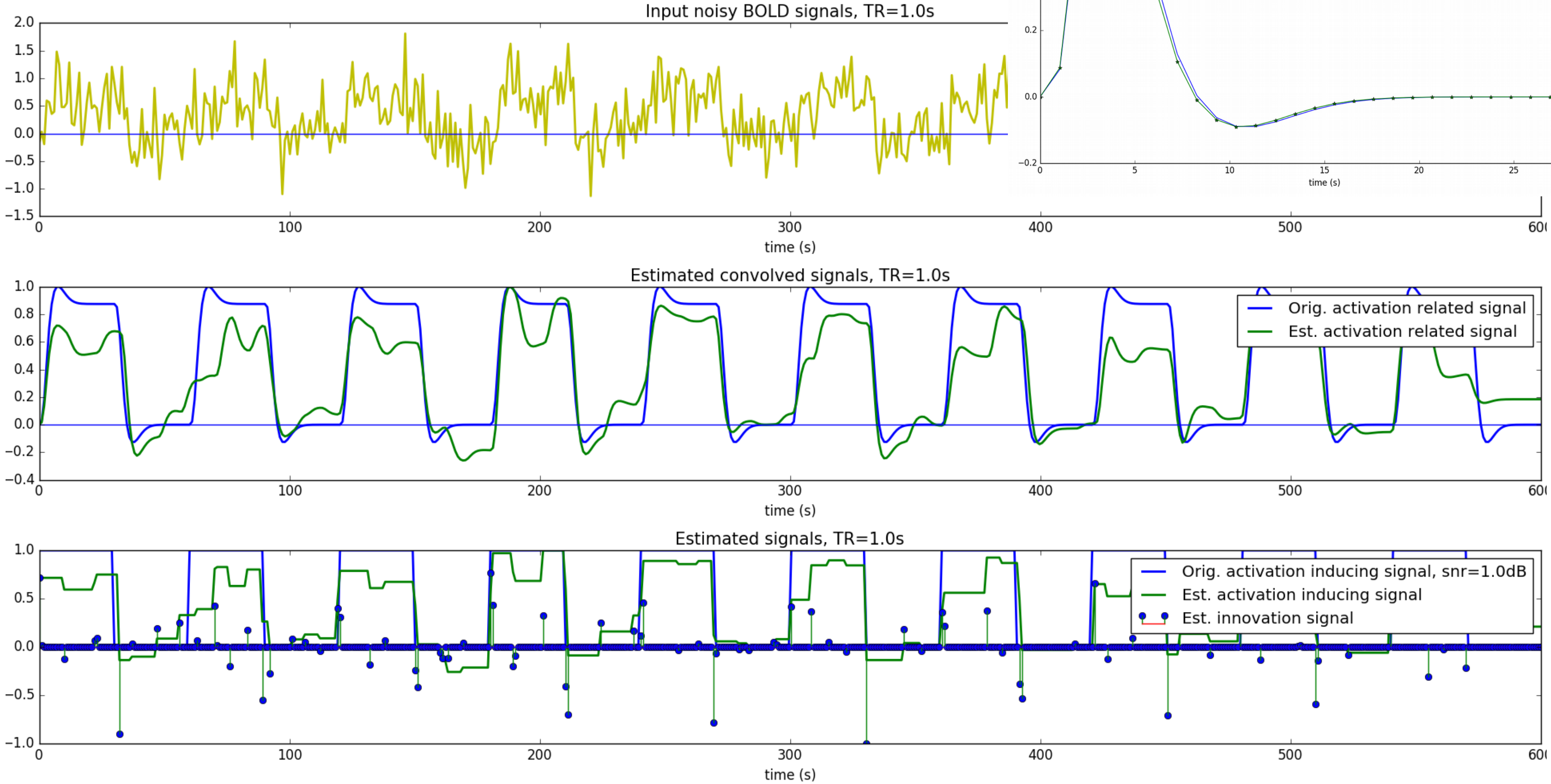
VALIDATION ON SYNTHETIC FMRI DATA

Results:

Parameters of the experiment:

- generating **1** synthetic BOLD time series
- **SNR=1dB**, TR=1.0s, duration of 10min (n=600 scans)
- 10 blocks
- lbda manually set

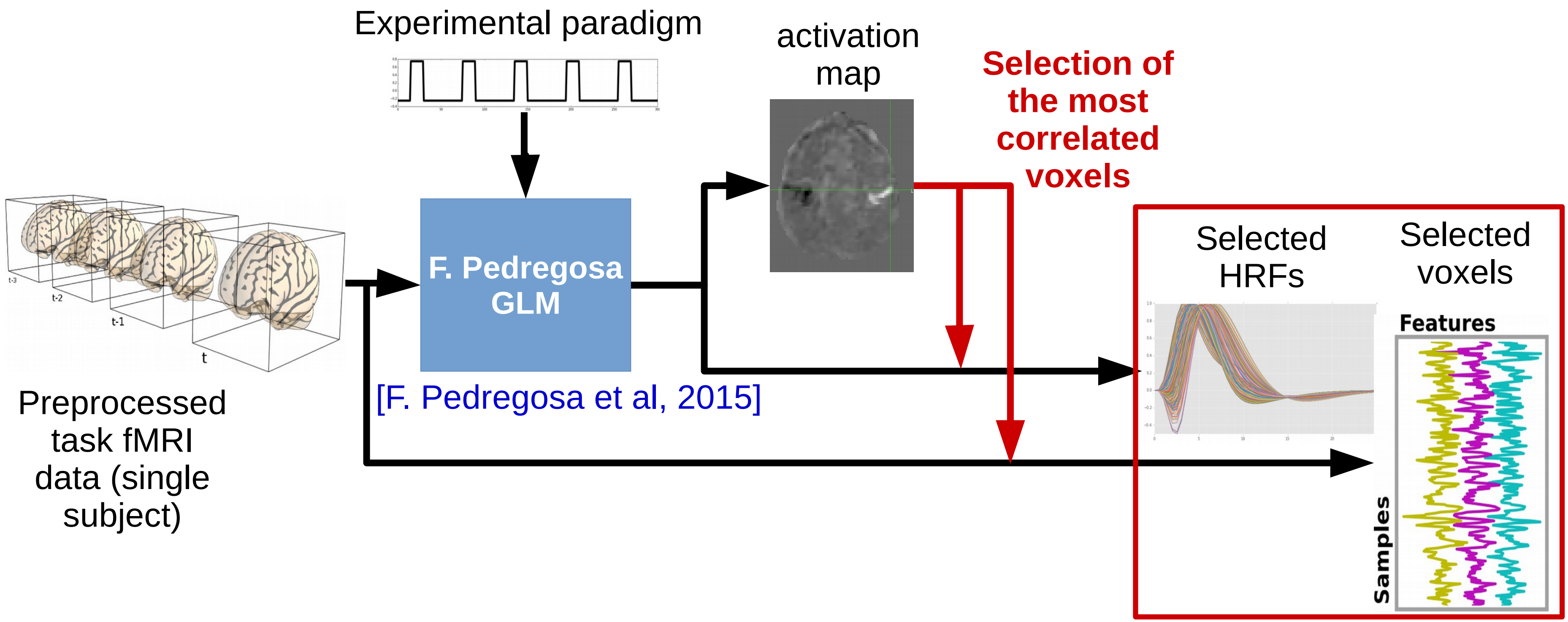




VALIDATION ON REAL FMRI DATA

Materials and methods:

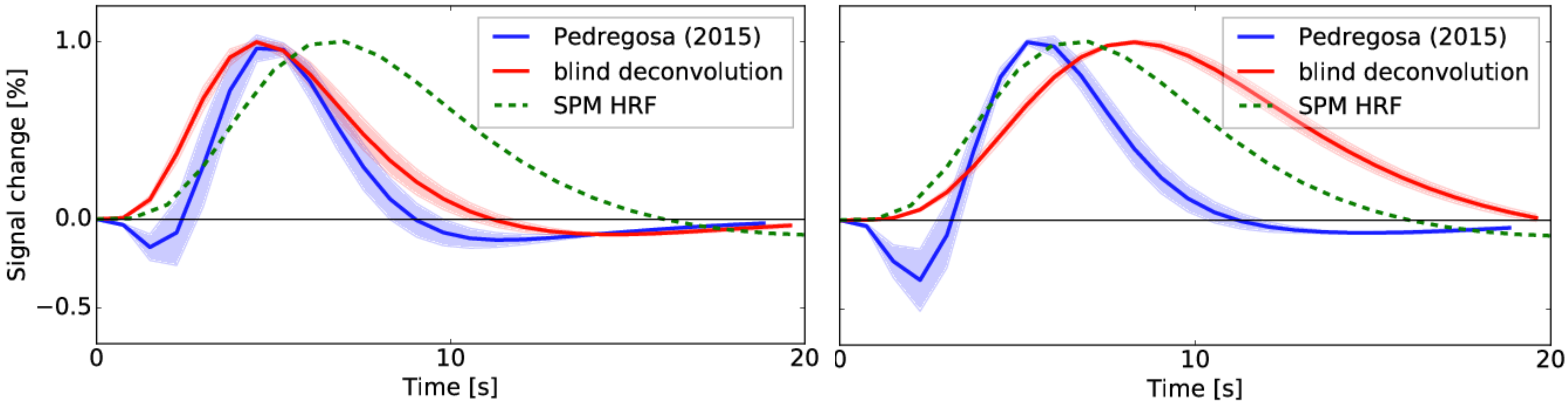
- Voxel selection process:



- **HCP data:**
  - HCP single subject; task of 3min34s; TR=0.75s; 284 time frames
  - 2 blocks of 12.0s for left hand motor tasks and 12 blocks of 2.0s for visual tasks

MATERIALS AND METHODS

Results:



Visual stimuli: **visual cortex**

Clenching left hand task: **right motor cortex**

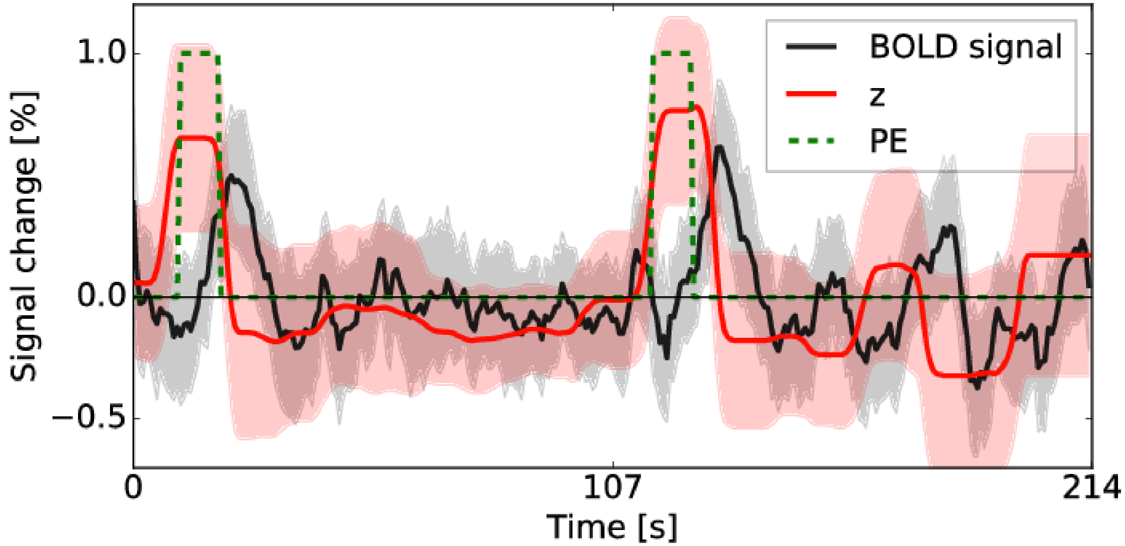
HRF estimates computed for two different tasks in one participant to the HCP protocol. The canonical SPM HRF, the reference HRF estimate and the HRF estimated using the proposed blind deconvolution technique.

What to notice:

Our technique adapts its estimation to the region eliciting evoked brain activity.

MATERIALS AND METHODS

Results:



Clenching left hand task: **right motor cortex**

Neural activity surrogates normalized by their infinity norm.
The standard deviation across voxels is encoded by transparency around mean curves for the EP, the preprocessed **BOLD signals y** in the most correlated voxels, and **the neural activation signals z** estimated with our blind deconvolution approach for the same voxels.

What to notice:

We counter-balance the haemodynamic delay as we align our neural activation signal with the EP

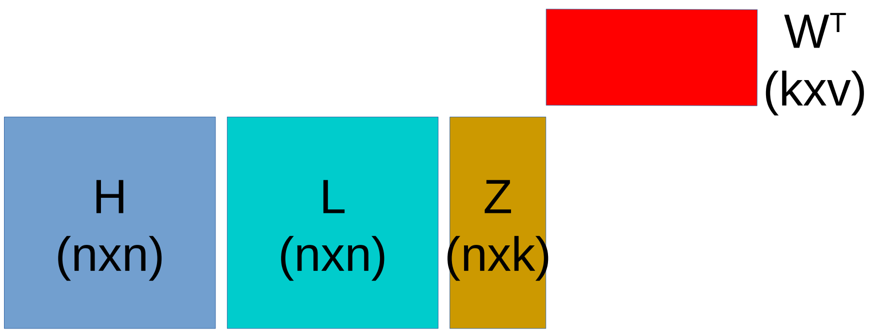
CONCLUSION

Conclusion:

- Proof of concept for the blind deconvolution of the BOLD signal
- More investigation on resting-state data
- No proper method to fix the regularization parameters
- univariate approach...

Multivariate extension:

$$Y = HLZW^T + E$$



H being a **fixed** Toeplitz matrix
L being a fixed lower triangular matrix
Z gather the temporal ‘atoms’
W being the corresponding spatial maps
E being a Gaussian matrix (noise)

REFERENCES

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Thank you