Spatiotemporal pattern extraction in functional neuroimaging

Hana Sebia(1), Thomas Guyet(1), Hugues Berry(1) and Benjamin Vidal(2)
(1) AIstroSight, Centre de recherche Inria de Lyon, France (2) Université Claude Bernard Lyon 1, Villeurbanne, France

SWoTTeD

Context

- **Brain activity** requires tools to analyse **signal dynamics**
- **Existing methods** (eg QPP[1] , ICA[2],…) rely on **strong assumptions** (recurrence, independance, spatial priors,…)

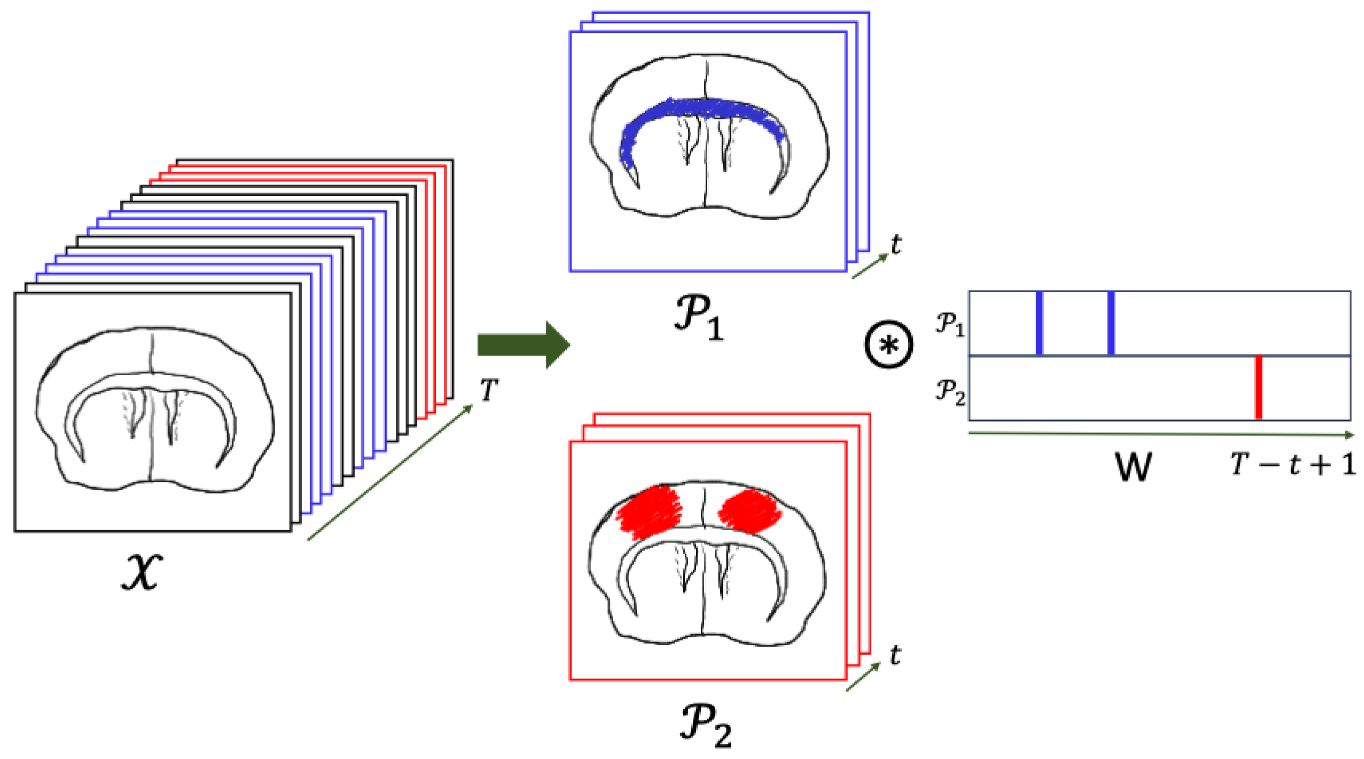
[1] Majeed W. et al. Spatiotemporal dynamics of low frequency BOLD fluctuations in rats and humans. NeuroImage, 54:1140–1150, 2011
[2] Meyer-Bäse L. et al. Spatiotemporal patterns of spontaneous brain activity: a mini-review. Neurophotonics, 9:032209, 2022

Contribution

- Adaptation of a **tensor decomposition** framework «**SWoTTeD** » for **spatiotemporal pattern** extraction in **functional neuroimaging**
- SwoTTeD opperates **without prior assumtions**, detecting both **recurrent** and **rare** neural events
- Applied to functional ultrasound (fUS), it reveals **activation patterns** linked **to visual stimulation**

Sliding Window for Temporal Tensor Decomposition - SWoTTeD* -

- Given $\mathcal{X}$, a 3D **brain imaging** stack containing T **2D** frames
- SWoTTeD extracts K **temporal patterns**, $\mathcal{P}$, of **duration t**
- $\mathcal{W}$ exhibits **the occurrences** of patterns $\mathcal{P}$ in the stack $\mathcal{X}$



* Sebia H. et al. : an extension of tensor decomposition to temporal phenotyping. Machine Learning, 113(9):5939–5980, 2024. Swotted

Minimisation Problem

$$\ell = \mathcal{L}(\hat{\mathcal{X}}, \mathcal{X}) + \alpha\|\mathcal{P}\|_1 + \beta\, \mathcal{S}(\mathcal{W}) + \gamma\, \mathcal{R}_{\perp}(\mathcal{P})$$

- $\mathcal{L}(\hat{\mathcal{X}}, \mathcal{X})$ is the **reconstruction error** described as the **distance** between the **ground-truth** $\mathcal{X}$ and the **reconstruction** $\hat{\mathcal{X}} = \mathcal{P} \circledast \mathcal{W}$
  - $\circledast$ is **a convolutional** operator
- $\|\mathcal{P}\|_1$ enforces **sparsity regularization** on **patterns** to focus on relevant signal changes
- $\mathcal{S}(\mathcal{W})$ is a pattern **non-succession regularization** term, penalizing reconstructions that **reuse** the **same** pattern within the **same window t**
- $\mathcal{R}_{\perp}(\mathcal{P})$ is an **orthogonality regularization** to enforce patterns to be as **distinct** as possible

Validation Framework

- Applied on **functional ultrasound** imaging (fUS) acquired from **rat brain** under **visual stimulation**
  - Varied the **number of extracted patterns K** in {2, 5, 10)
  - Varied **the duration of extracted patterns t** in {50, 75,100) frames
- Compared to **Block Tensor Decomposition (BTD)**

Evaluation Metric

$$FIT = 1 - \frac{\sum_{i=1}^{T}\|X^{(i)} - \hat{X}^{(i)}\|}{\sum_{i=1}^{T}\|X^{(i)}\|}$$

Quality of Recontruction

K	SWoTTeD t	SWoTTeD Mean FIT	BTD Mean FIT
2	50	0.0028 ± 0.007	0.030 ± 0.001
	75	0.0030 ± 0.005	
	100	0.0036 ± 0.001	
5	50	0.0034 ± 0.01	0.038 ± 0.001
	75	0.0042 ± 0.004	
	100	0.0051 ± 0.006	
10	50	0.0043 ± 0.006	0.042 ± 0.001
	75	0.0054 ± 0.001	
	100	0.0063 ± 0.008	

- ➢ **Increasing** the number of patterns **K**, or their duration **t**, **improves** the recontruction
- ➢ The reconstruction of **BTD** is **significantly better**

Quality of Spatiotemporal Patterns

- **Both** SWOTTED and BTD **detect activation** in **the superior colliculus** and **visual cortex** during **visual** stimulation
- **BTD** provides **static spatial maps** and their associated **temporal signals**
- **SWOTTED** extracts full spatiotemporal patterns as **sequences** of frames
- It reveals **dynamic propagation**: activation starts in the colliculus and spreads to the visual cortex

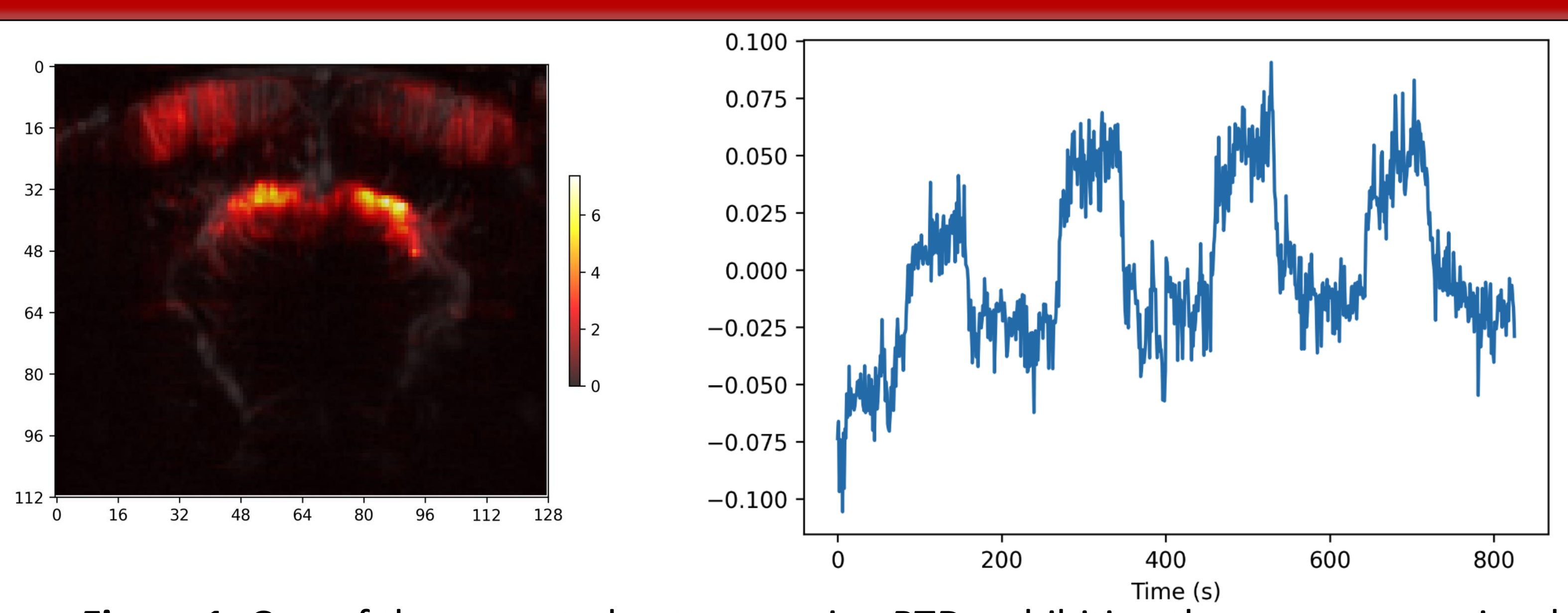


Figure 1: One of the extracted patterns using BTD, exhibiting the response to visual stimulation.

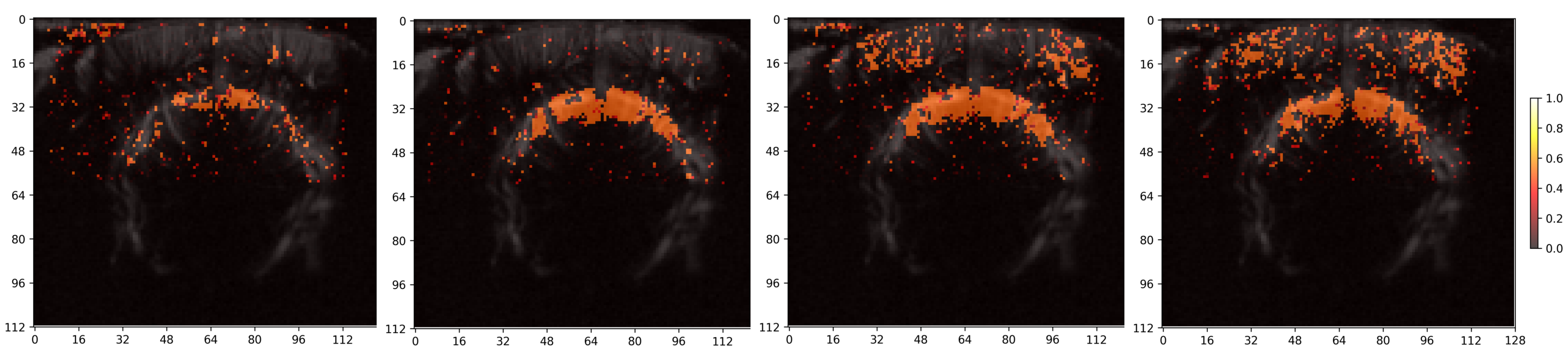


Figure 2: Four frames of a spatiotemporal pattern extracted, using SWoTTeD, from fUS under visual stimulation, showing signal evolution from left to right in response to the stimulus across different brain regions.