LDFA-H: Latent Dynamic Factor Analysis of High-Dimensional Neural Recordings

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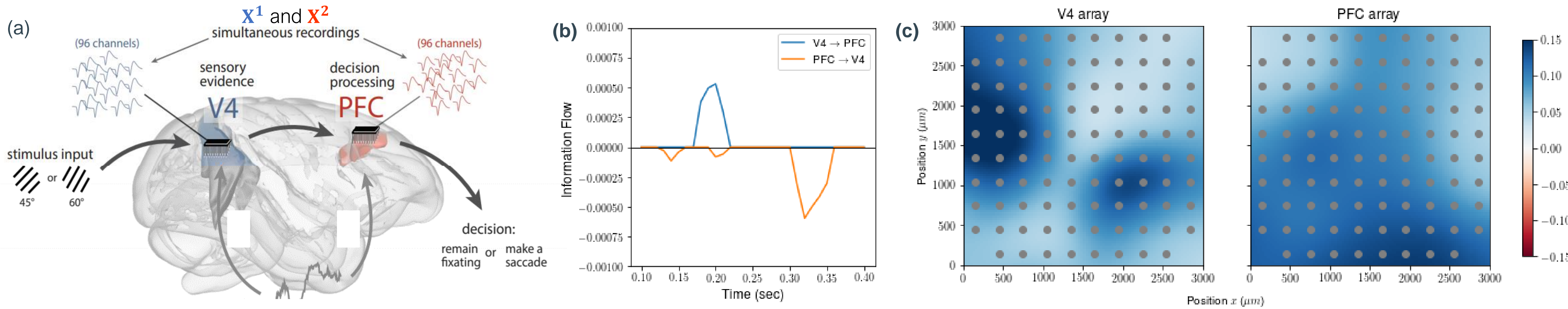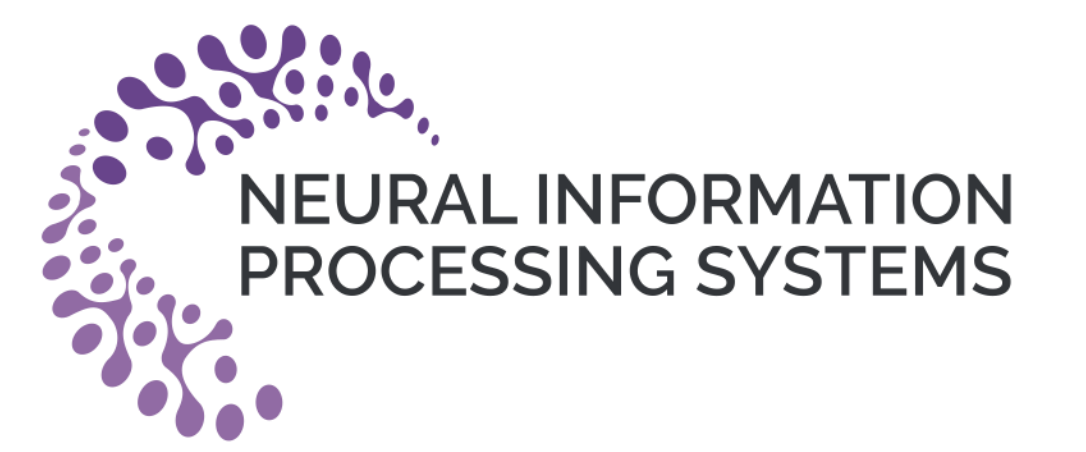
NEURAL INFORMATION PROCESSING SYSTEMS

Figure 1: LDFA-H captures non-stationary spatio-temporal association between brain areas

(a) Multivariate neural time-series X^1 and X^2 from arrays in macaque monkey V4 and PFC [1]

(b) Dynamic information flow in directions V4→PFC and PFC→V4

(c) Corresponding spatial factor loadings on arrays

Experiment: Memory-guided saccade task

Data: Simultaneous multi-variate time-series X^1 and X^2 from 2 brain areas in repeated trials; see Fig. 1a and [1]

Goal: Estimate dynamic between-areas interactions

LDFA-H model

1. Dynamic associations between X^1 and X^2 are summarized by q-dimensional latent time-series Z^1 and Z^2.

$$X^k_{:,t} \mid Z^k_{:,t} = \mu^k_{:,t} + \beta^k \cdot Z^k_{:,t} + \epsilon^k_{:,t}, t = 1, \dots, T, k = 1, 2$$

$$\begin{pmatrix} Z^1_{f,:} \\ Z^2_{f,:} \end{pmatrix} \sim \mathrm{MVN}(0, \Sigma_f), f = 1, \dots, q$$
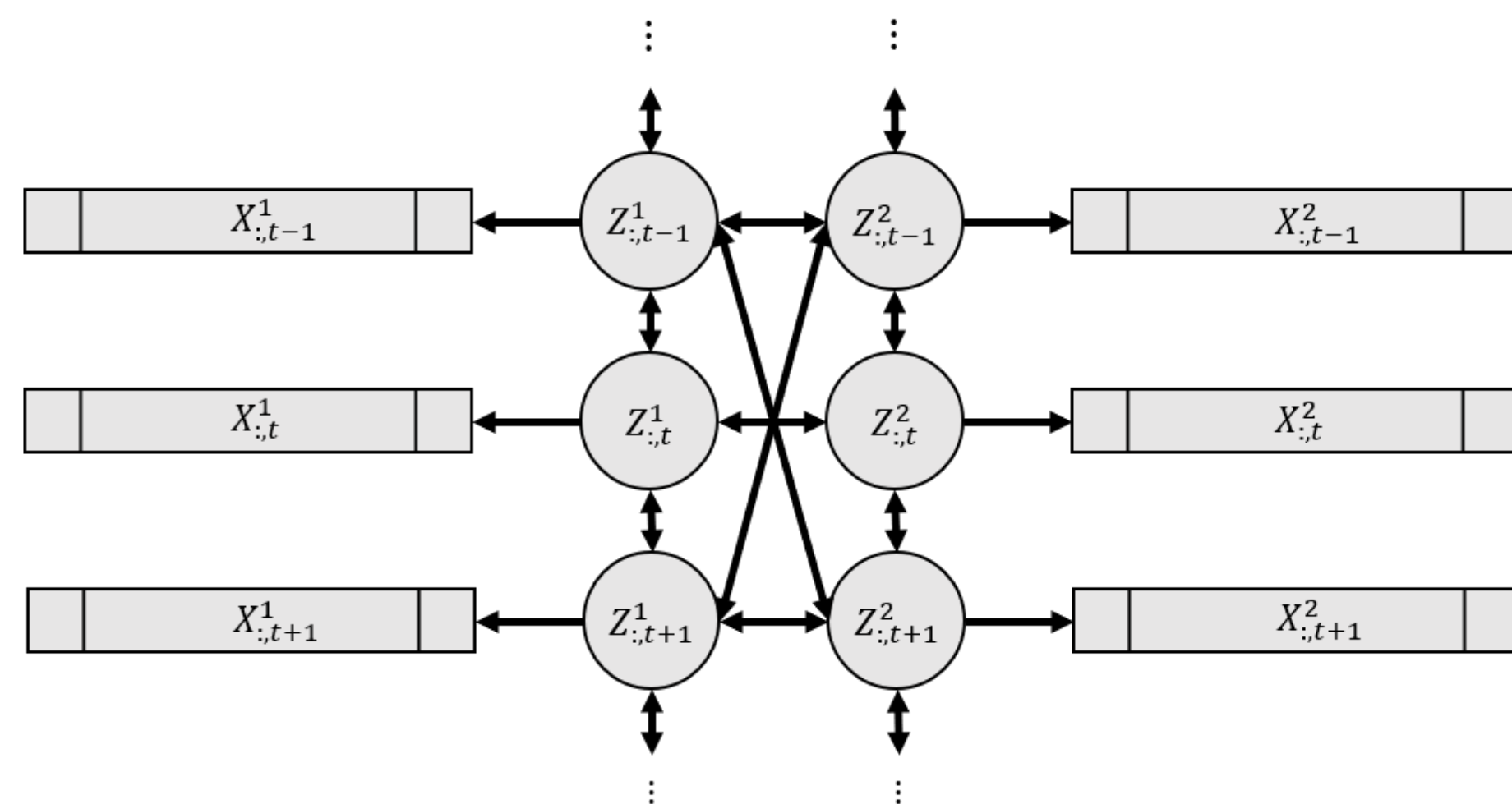
Figure 2: LDFA-H model. Arrows between Z^1 and Z^2 represent potential associations between X^1 and X^2.

2. **Matrix-variate assumption** on within-area spatiotemporal dependence reduces the parameter dimension.

$$\mathrm{Vec}(\epsilon^k) = (\epsilon^k_{:,1}; \epsilon^k_{:,2}; \dots; \epsilon^k_{:,T}) \sim \mathrm{MVN}(0, \Phi^k_{\mathcal{T}} \otimes \Phi^k_{\mathcal{S}}), k = 1, 2$$

3. Sparsity constraints on $(\Phi^k_T)^{-1}$ and $(\Sigma_f)^{-1}$ further reduces dimensionality and resolves identifiability issues.

Inference

Inference based on inverse correlation matrix Π_f corresponding to Σ_f.

Significant element of Π^{12}_f (e.g. red star in Fig. 3)

- coordinates → time at which connectivity happens
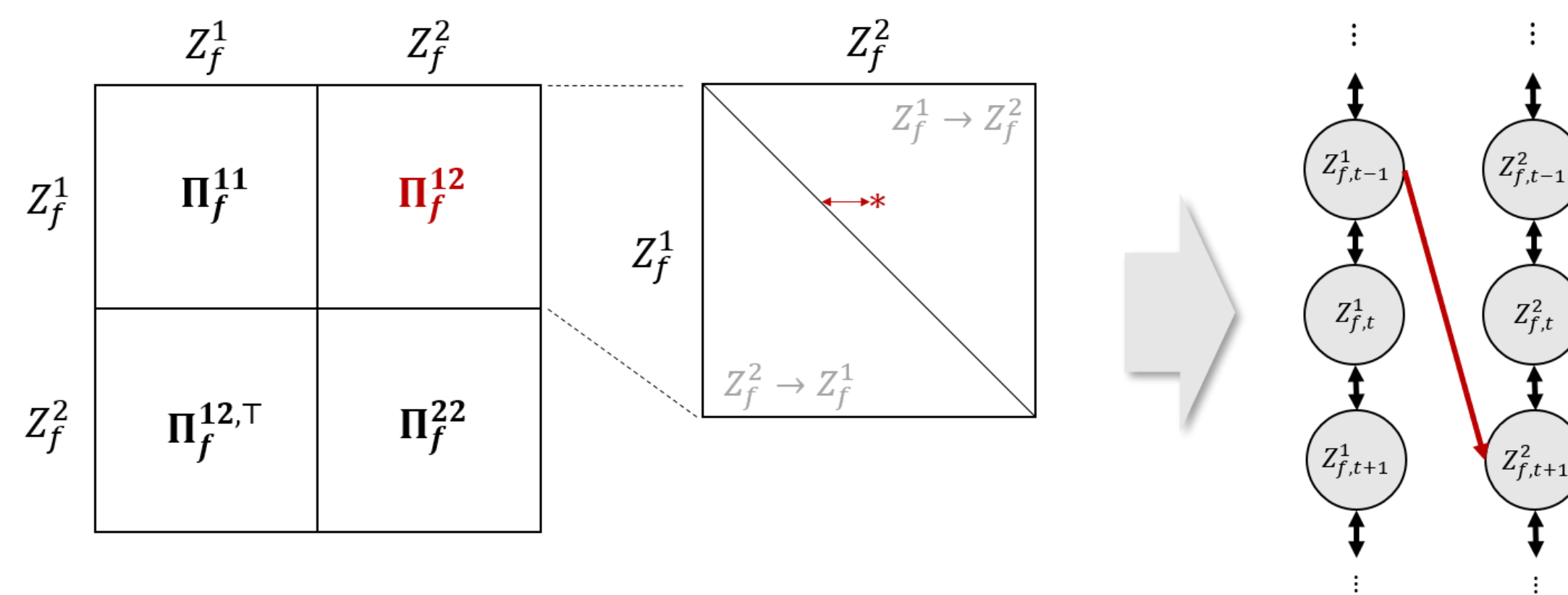- distance from diagonal → connectivity lead or lag

Figure 3: Graph interpretation of connectivity from inverse correlation Π_f

Experimental results

1. Estimated inverse cross-correlation matrix Π^{12}_f of the dominant factor suggests associations between V4 and PFC
   - V4→PFC around 200 ms at lag $\approx$ 20ms
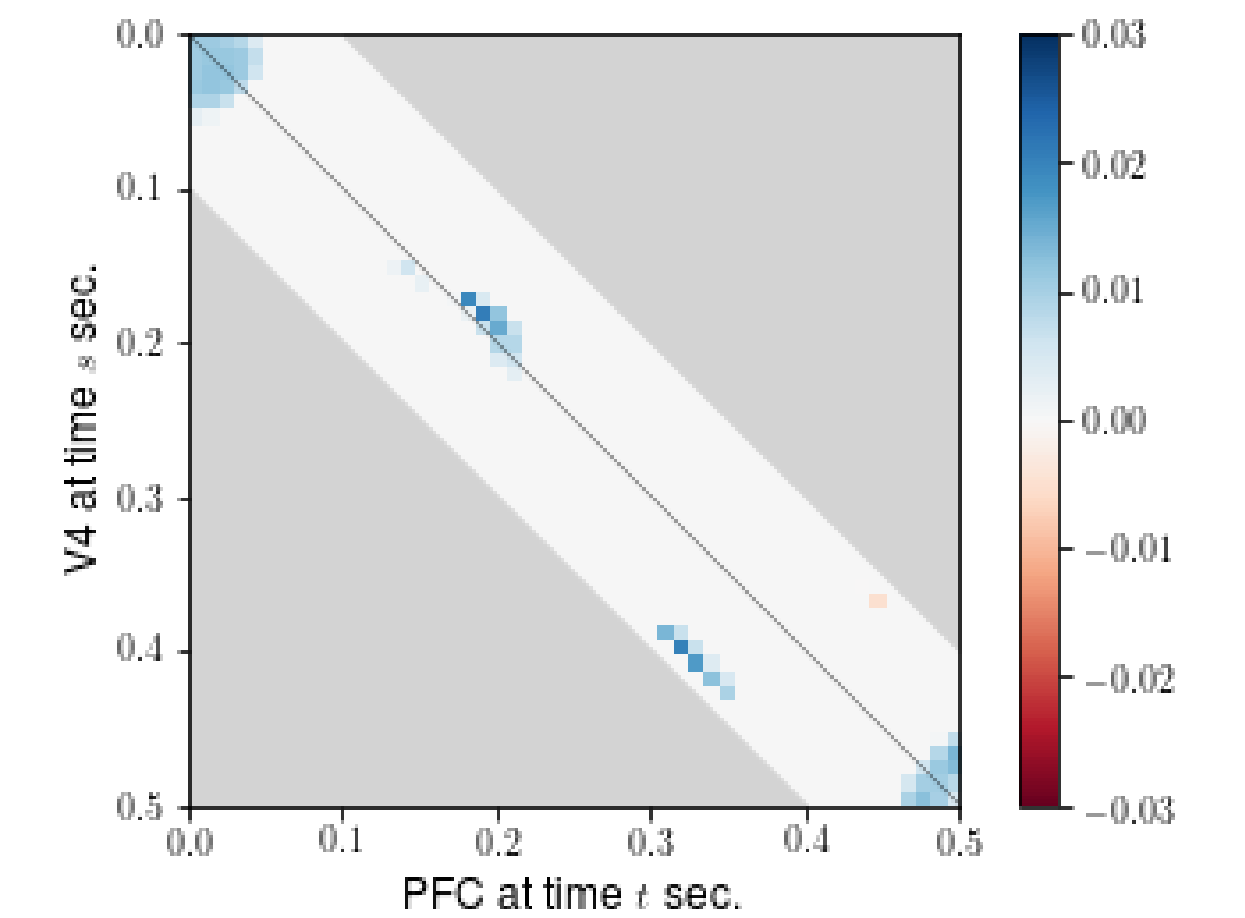   - PFC→V4 around 320 ms at lag $\approx$ 80ms

Figure 4: Π^{12}_f estimate

2. Fig. 1b shows the information flow based on Π^{12}_f.

3. Factor loadings in Fig. 1c show different spatial modes over the physical space of the Utah arrays.

Reference:
[1] Khanna, S. B., Scott, J. A., and Smith, M. A. (2020). Dynamic shifts of visual and saccadic signals in prefrontal cortical regions 8Ar and FEF. Journal of Neurophysiology. In press.