Modeling Dynamic Functional Connectivity with Latent Factor Gaussian Processes

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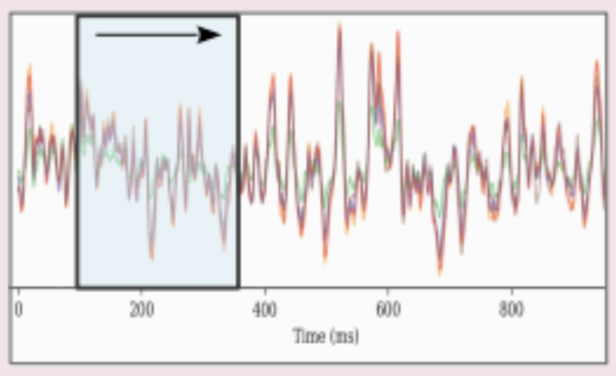
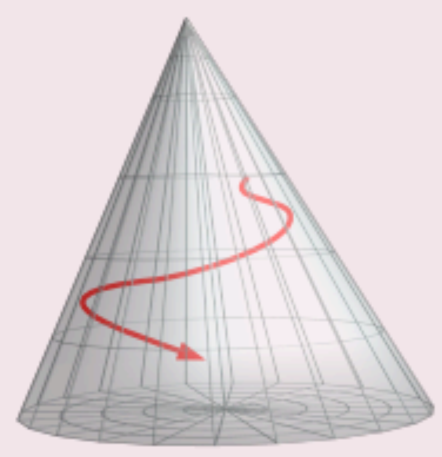
Observed LFP Signals



The covariance process from a non-stationary multivariate time series is obtained by **sliding window estimation**.

SW

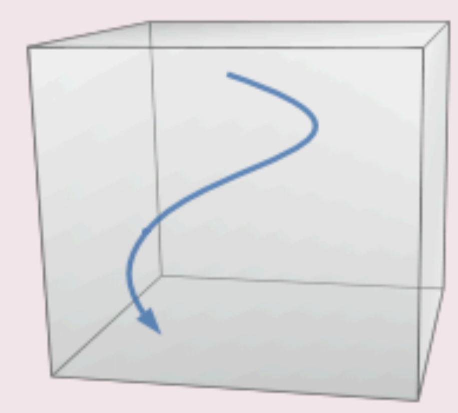
Cov. Process on $\mathbf{P}_p$



The estimated covariance process is a trajectory in the **manifold of symmetric positive definite matrices**.

Log

Log Process on $\mathbb{R}^q$



Applying the matrix logarithm maps to the covariance process to a **path in Euclidean space.**

LFGP

Latent Space Representation

Estimate a low-dimensional **latent space representation** of the log-covariance process.

LFGP Model

- Dynamic functional connectivity (DFC), as measured by the time-varying covariance of neurological signals, is important for cognition.
- *Stochastic process Xi(t) with covariance Ki(t); log-covariance Yi(t) as a linear combination of latent factors Fi(t).*

$$X_i(t) \sim \mathcal{D}(0, K_i(t)) \text{ where } K_i(t) = \exp\left(\vec{\mathbf{u}}(Y_i(t))\right)$$
$$Y_i(t) = F_i(t) \cdot B + \epsilon_i \text{ where } \epsilon_i \sim \mathcal{N}(0, I\sigma^2)$$
$$F_i(t) \sim \mathcal{GP}(0, \kappa(t;\theta))$$
$$B \sim p_1, \sigma^2 \sim p_2, \theta \sim p_3$$

- Naturally allows for inference of scientific hypotheses, inclusion of prior information, and visualization of connectivity dynamics.

Simulation Study

- Data generated with latent covariance dynamics: square waves, piecewise linear, and cubic splines.
- Compare with sliding window and principal component analysis, hidden Markov model, and latent factor stochastic volatility model.

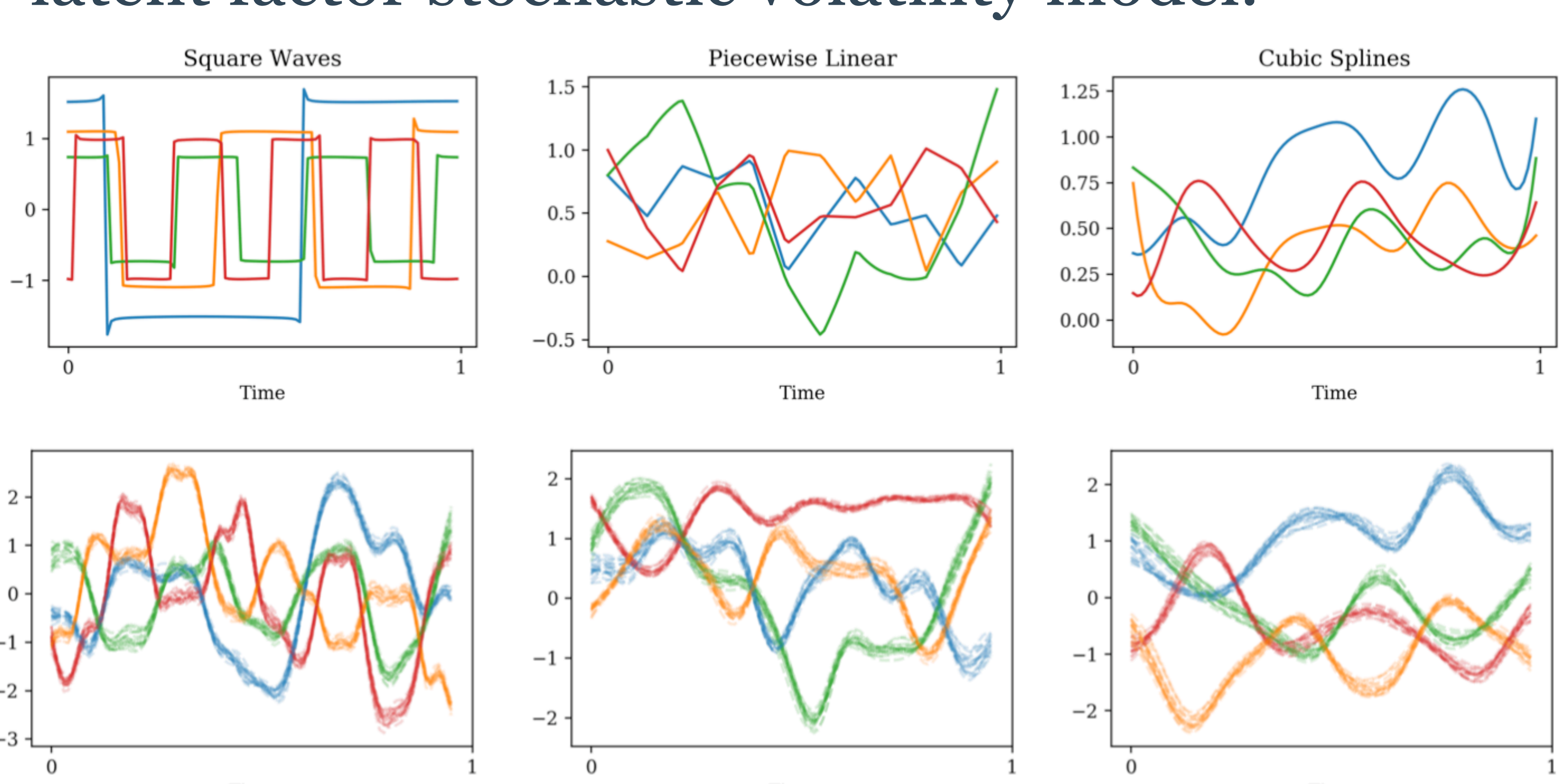
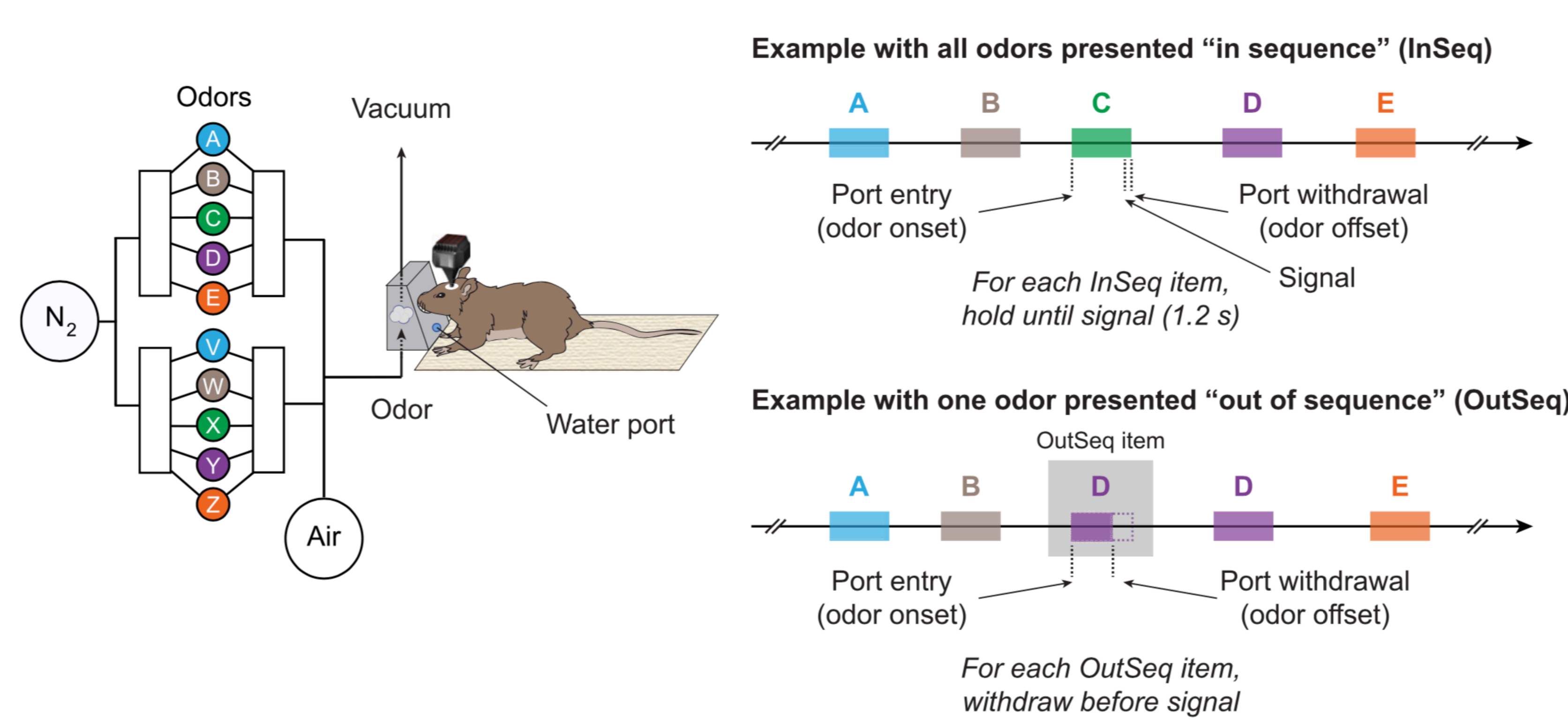


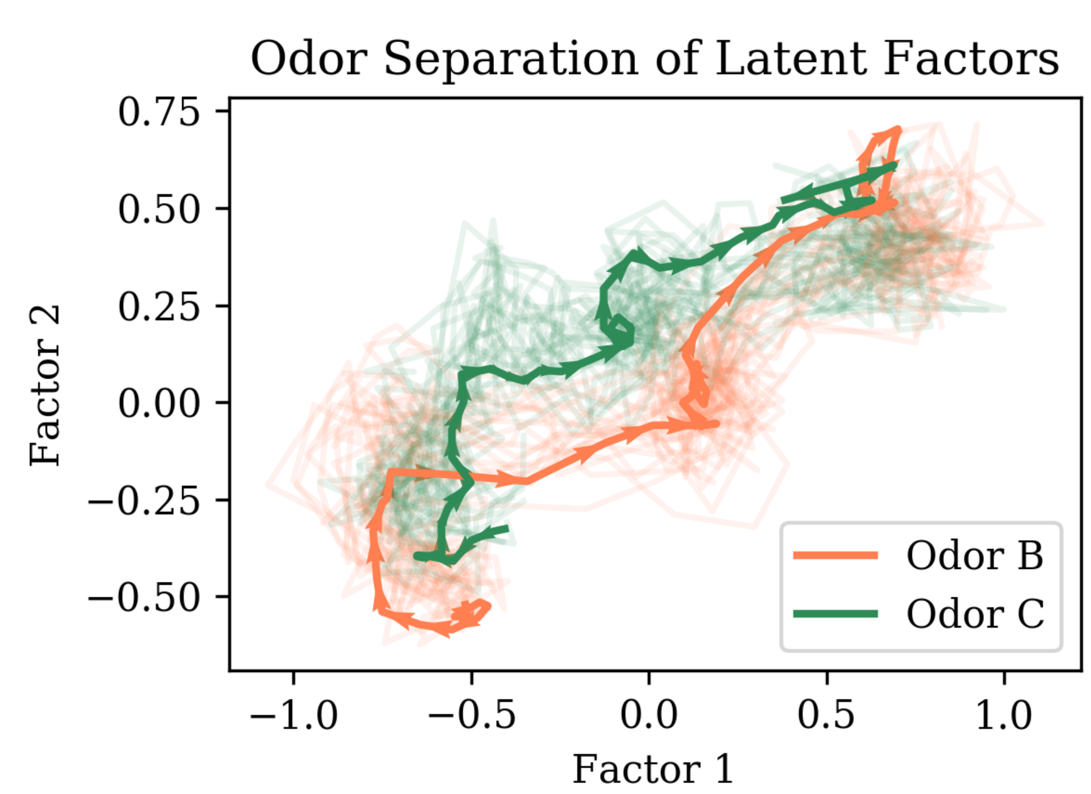
Table 2: Median reconstruction loss (standard deviation) across 100 data sets

	SW-PCA	HMM	LFSV	LFGP
Square save	0.693 (0.499)	1.003 (1.299)	4.458 (2.416)	0.380 (0.420)
Piece-wise	0.034 (0.093)	0.130 (0.124)	0.660 (0.890)	0.027 (0.088)
Smooth spline	0.037 (0.016)	0.137 (0.113)	0.532 (0.400)	0.028 (0.123)

LFP Data Analysis



- Local field potentials from the rat hippocampus during non-spatial memory task.
- Latent factor posteriors show theta oscillation, non-stationary covariance of LFP, and separation of different stimuli.



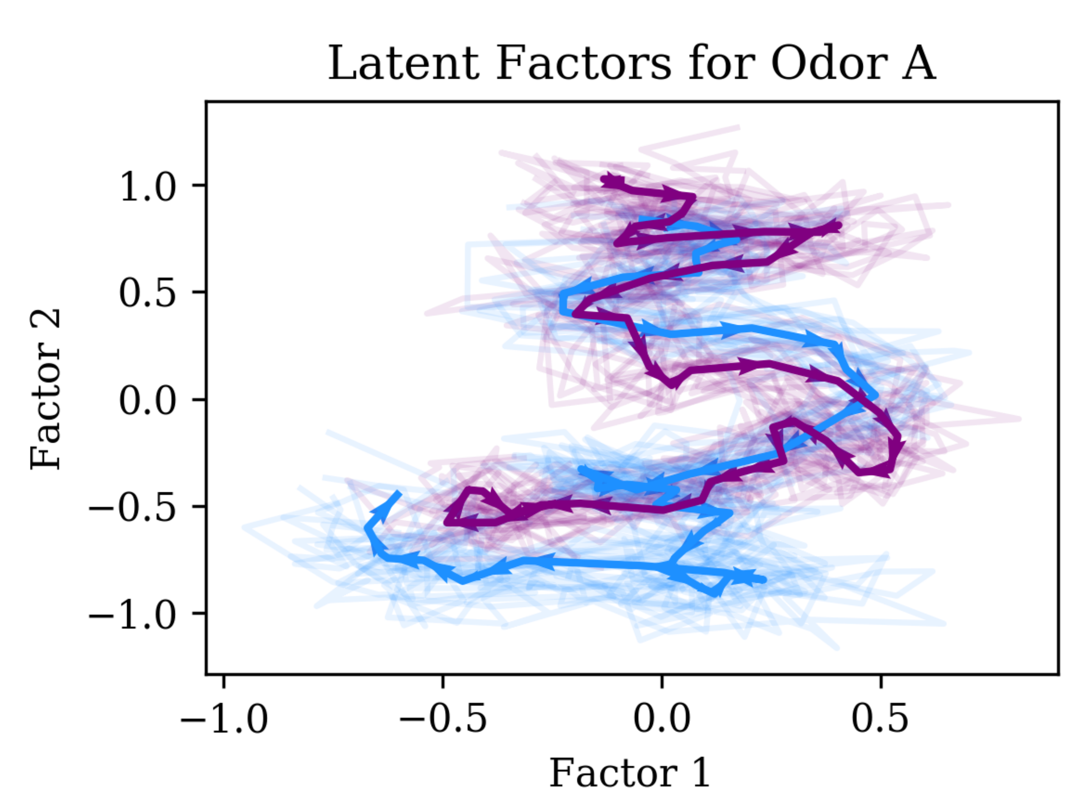


Table 3: Latent space classification accuracy (standard deviation)

	Different odors	Same odor
Logistic regression	69.97 (0.78)	63.10 (0.91)
k-NN	87.12 (0.33)	78.41 (0.65)
SVM	74.53 (0.67)	64.75 (1.21)