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Flow Matching for Few-Trial Neural Adaptation with Stable Latent Dynamics

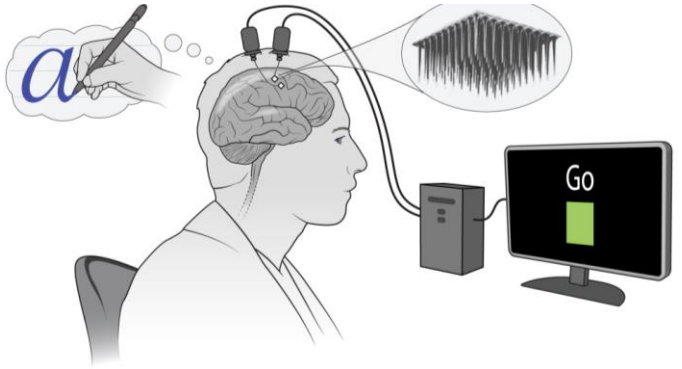
Puli Wang [1,2], Yu Qi [2,3 *], Yueming Wang [1,2], Gang Pan [1,2 *]

[1] College of Computer Science and Technology, Zhejiang University
[2] State Key Lab of Brain-Machine Intelligence, Zhejiang University
[3] MOE Frontier Science Center for Brain Science and Brain-Machine Integration, Zhejiang University

Background

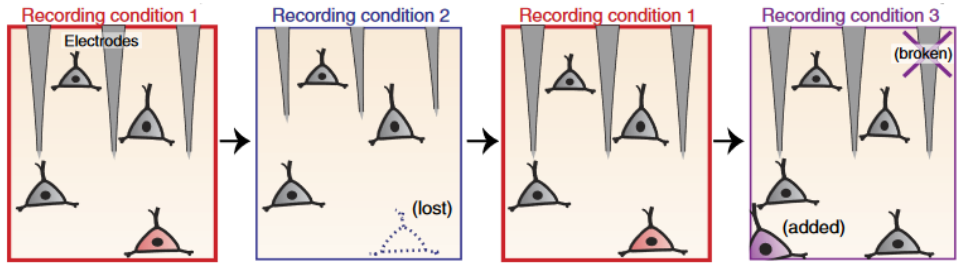
- The **brain-computer interfaces (BCIs)** aim to establish a direct linkage between neural activities and behavioral actions via neural decoders.

[1]



- Sustaining **long-term** decoding performance in chronic implantation is challenging due to the **nonstationary property** of neural signals.

[2]

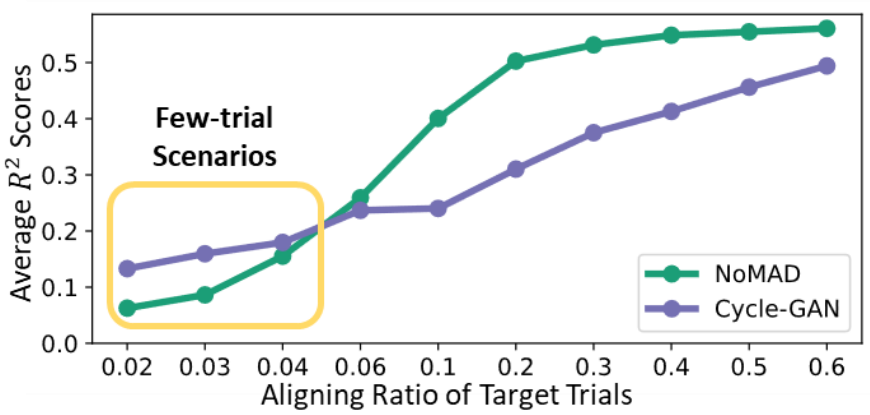


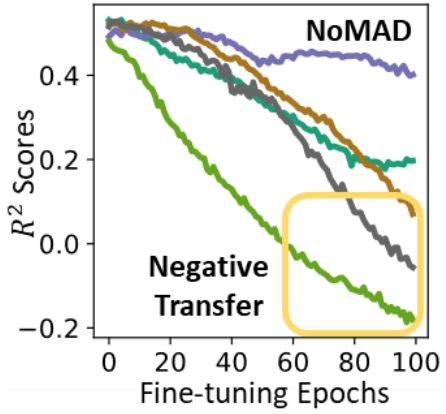
[1] WILLETT, Francis R., et al. High-performance brain-to-text communication via handwriting. Nature, 2021, 593.7858: 249-254.
[2] Sussillo D, Stavisky S D, Kao J C, et al. Making brain–machine interfaces robust to future neural variability. Nature communications, 2016, 7(1): 1-13.

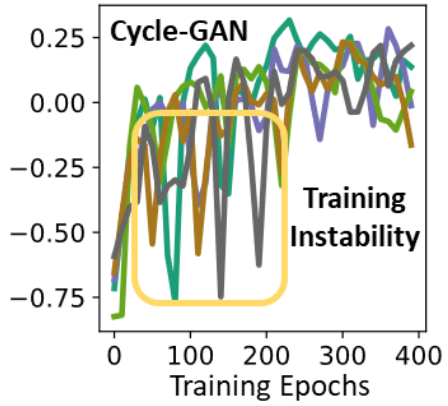
Background

- Improving neural alignment in **few-trial scenarios** for real-world BCI deployment.

- Invalid assumptions on **prior distributions** (NoMAD [1]).
- Ustable training based on certain **objective functions** (Cycle-GAN [2]).







[1] KARPOWICZ, Brianna M., et al. Stabilizing brain-computer interfaces through alignment of latent dynamics. Nature Communications, 2025, 16.1: 1-17.
[2] MA, Xuan, et al. Using adversarial networks to extend brain computer interface decoding accuracy over time. elife, 2023, 12: e84296.

Motivation

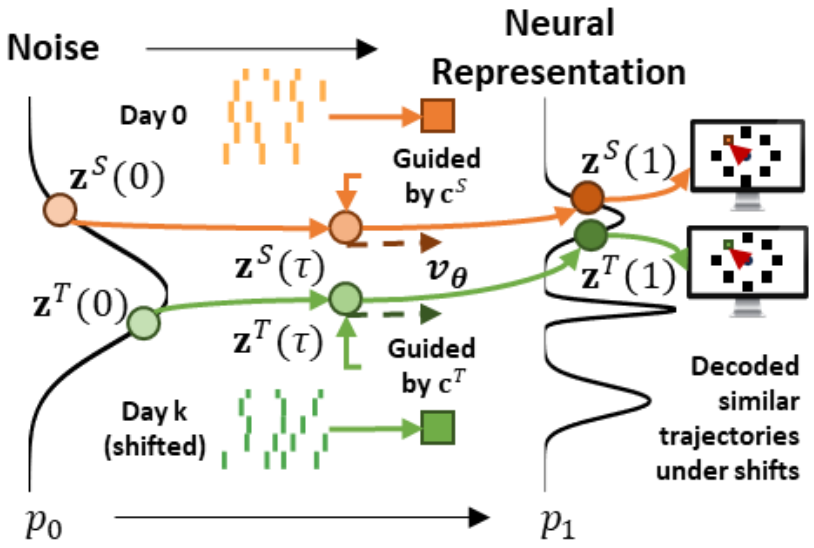
☐ Flow matching is suitable for neural adaptation in **few-trial scenarios**.

➢ **Prior Stationary distributions.**

- **Finding 1:** Flow matching can learn stable neural representations with **flexible distributions**.

➢ **Ustable objective functions.**

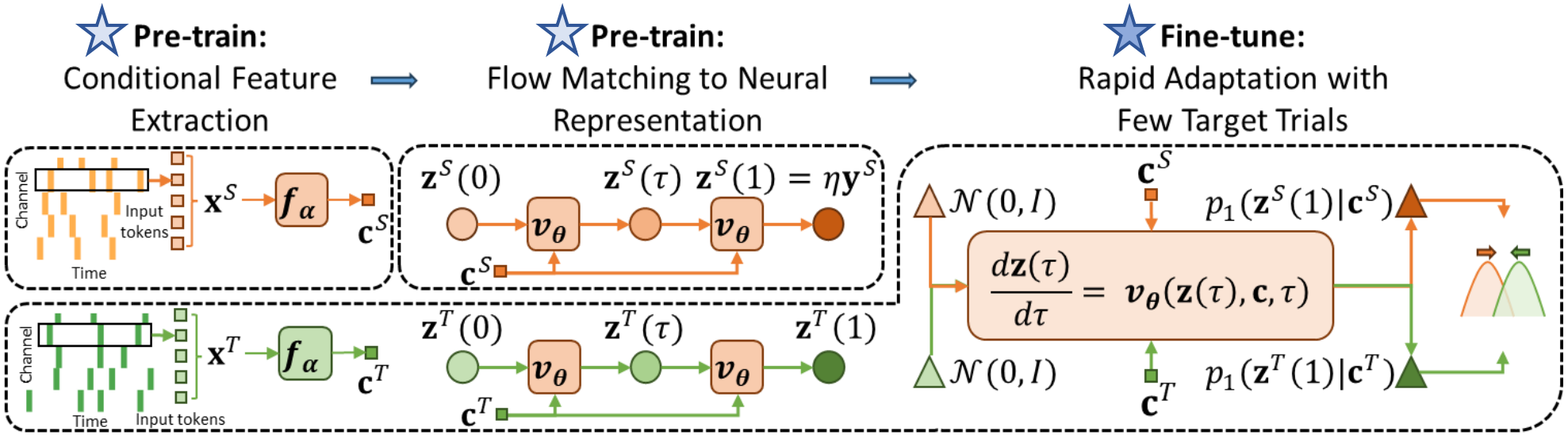
Finding 2: Flow-based models also enables rapid adaptation through **direct likelihood maximization**.



Method

- Proposed Flow-Based Distribution Alignment (FDA) based on flow matching.

- **Pre-train: (1)** Extracting c from x **(2)** Generating $z(1)$ from $z(0)$ guided by c
- **Fine-tune:** Aligning the conditional distribution of $z^S(1)$ and $z^T(1)$



Results

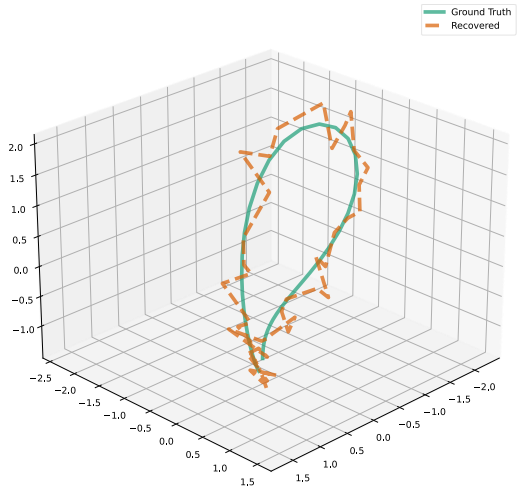
Simulated results on Lorenz attractor.

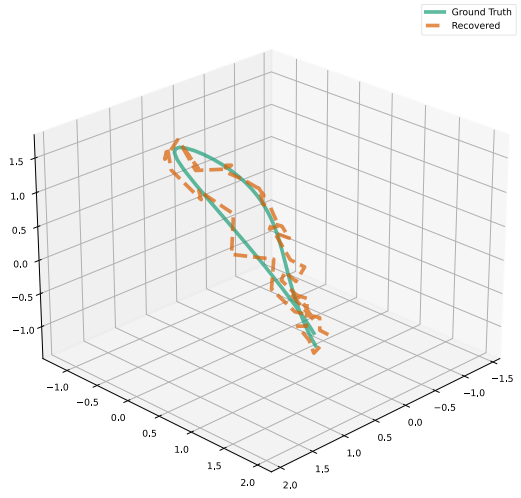
- Average R^2 at varying firing rates.

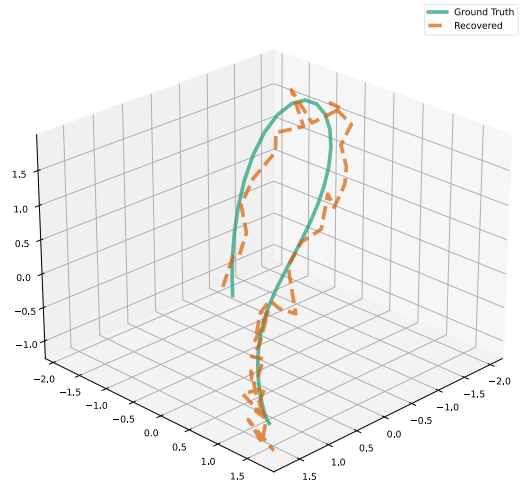
Table 3. Average R^2 scores(%) for recovered latent variables from synthetic spiking data at varying mean firing rates.

Mean Firing Rates	0.05	0.1	0.3
R^2	$95.43_{\pm 0.87}$	$95.68_{\pm 1.07}$	$95.24_{\pm 1.03}$

- Visualization results.



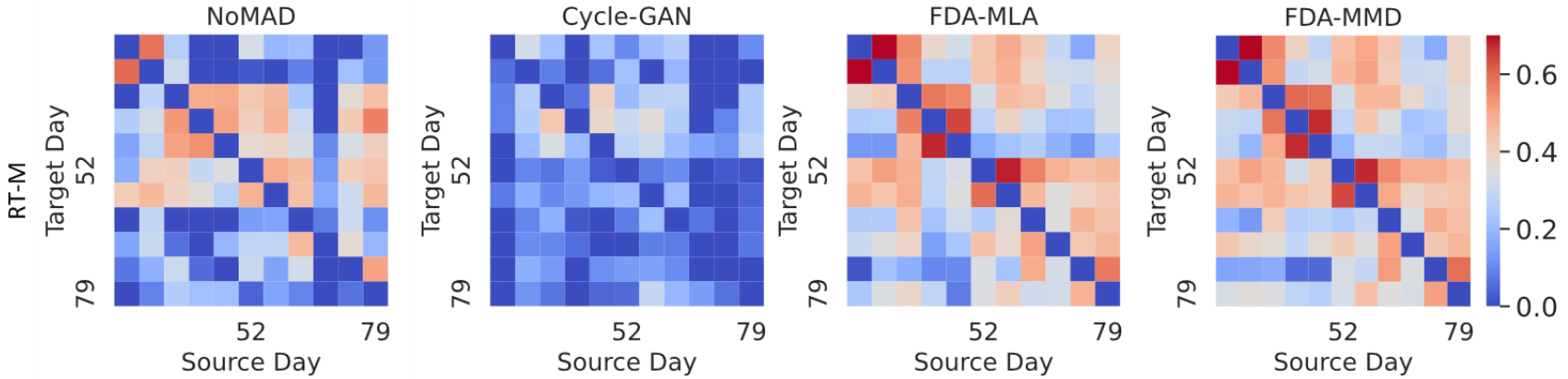




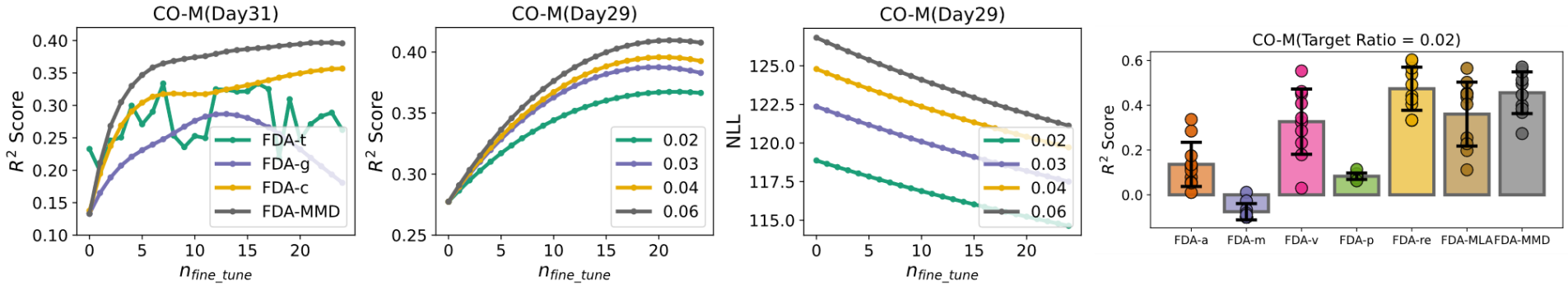
Results

Results on motor cortex datasets[1].

- Comparative study to SOTA on cross-session decoding performance.



- Ablation study on alignment strategies and main components.



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Thank you!

Puli Wang, Yu Qi, Yueming Wang, Gang Pan

E-mail: wangpuli@zju.edu.cn

Zhejiang University, Hangzhou, China