Active Learning of Neural Stimulation Dynamics for Brain-Computer Interfaces

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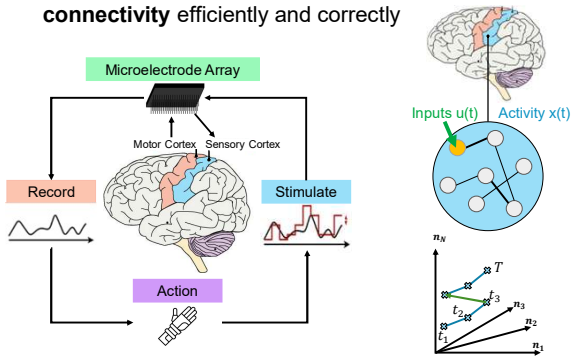
AIMS

- Create **Bi-directional Brain-Computer Interfaces**

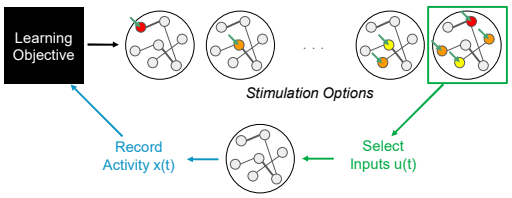
  BCI: Devices controlled via recorded neural activity

  Bi-directional: Give feedback through brain stimulation
- Need to **infer stimulation effects** and **neural connectivity** efficiently and correctly

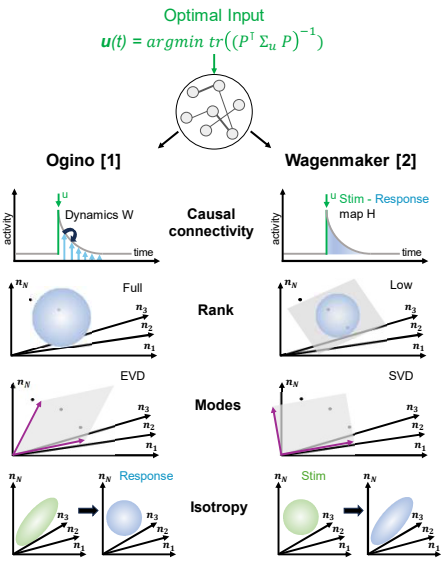


ACTIVE LEARNING OF STIMULATION EFFECTS

Choose best stimulation online given a learning objective:



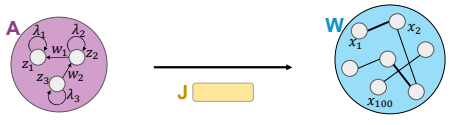
Two leaning objectives based on A-optimality so far:



Can we do better by combining and adapting them?

SIMULATION BENCHMARKING PLATFORM

Low-Rank Linear Dynamical System

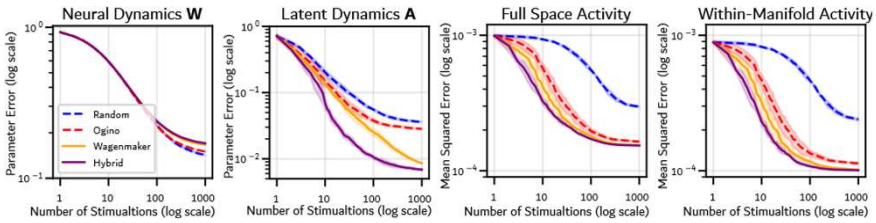


Define 3-D latent system $\tau \frac{dz}{dt} = Az(t) - z(t) + \tilde{B}u(t)$

Randomly Project $x = Jz$

To get 100-D neural system $\tau \frac{dx}{dt} = Wx(t) - x(t) + Bu(t)$

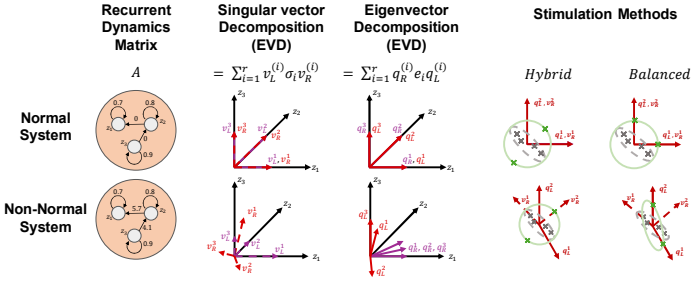
FASTEST LEARNING IS ACHIEVED BY OPTIMISING THE LOW-RANK W MATRIX



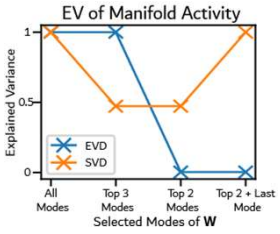
Using a Hybrid method which creates isotropic inputs (Isotropy; Wagenmaker) along the top components (Rank / Modes; Wagenmaker) of the dynamics matrix **W** (Causal Connectivity; Ogino) requires the least number of stimulations to identify the latent system.

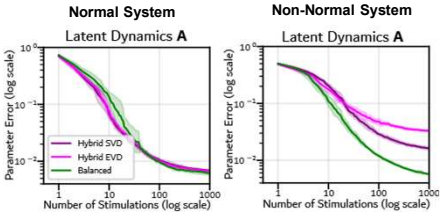
ORTHOGONAL INPUTS HINDER IDENTIFICATION OF NON-NORMAL DYNAMICS

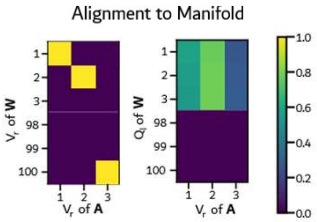
In non-normal systems the dynamic modes interact and amplify each other:



Leading to suboptimal performance when using A-optimality, since it requires orthonormal basis vectors but SVD does not capture the full Manifold. Instead, Balanced amplification of the identified left eigenvectors of the system is superior in system identification

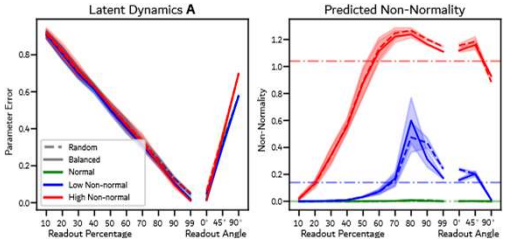






PARTIAL OBSERVATION LEADS TO MISIDENTIFICATION OF THE LATENT SYSTEM

Low observability leads to underestimation while medium observability results in overestimation of system non-normality without being reflected in connectivity estimation error. This is likely due to the readout angle to the right eigenvectors of the system.



CONCLUSION

- Learning objectives differ in what part of the system gets identified first
- Current objectives do not work for highly non-normal systems
- Proposed new Balanced method which performed best for non-normal and partially observed systems

FUTURE DIRECTIONS

- Proof optimality of proposed method theoretically
- Test proposed method experimentality
- Test whether inferred system are good enough for bi-directional BCIs

References:
[1] Ogino et al. BioRxiv (2025)
[2] Wagenmaker et al. NeurIPS 37 (2024)