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MesoGAN: behavior generation from neural decoding of mesoscale cortical calcium dynamics using Generative Adversarial Networks.

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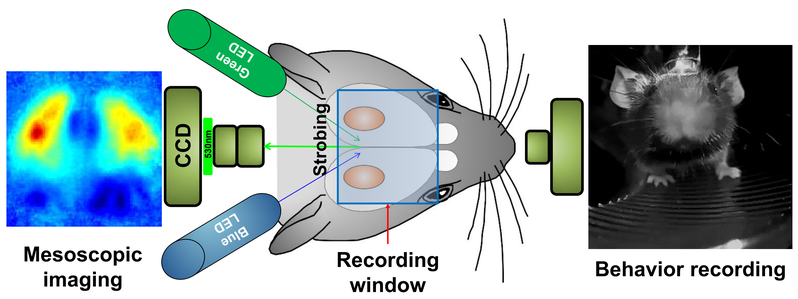
Introduction:

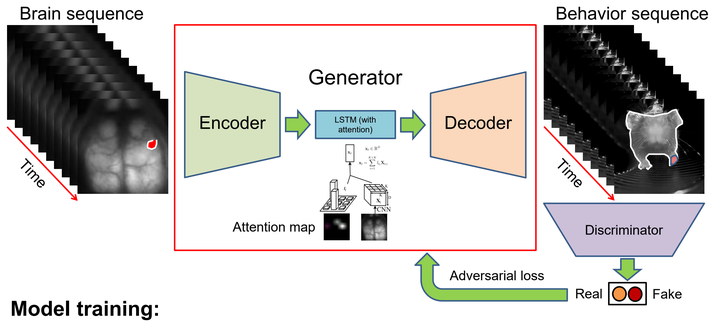
A cardinal objective in systems neuroscience entails elucidating the intricate relationship between neural activity and behavior. Historically, behavioral analysis has predominantly focused on low-dimensional, task-associated variables such as locomotion velocity or reaction times. However, burgeoning interest in the complex, nonlinear associations between brain function and high-dimensional behavioral data necessitates the development of innovative tools proficient in decoding real-world, brain-related high-dimensional data. In this study, we present MesoGAN, a sophisticated Generative Adversarial Network (GAN) tailored to synthesize authentic behavioral videos derived from the neural decoding of mesoscopic cortical calcium dynamics. Employing wide-field cortical calcium imaging, our model generates synthetic (predicted) behavioral videos. Our results demonstrate that the GAN-based approach can generate realistic fake behavioral videos that closely resemble the actual videos (brain to behavior). The framework can also be used to reconstruct brain activity from behavior video (behavior to brain). The attention maps produced by the GAN further pinpoint critical brain activity features that are highly predictive of specific bodily movements, thereby offering novel insights into the neural activity-behavior relationship. This research holds significant implications for fields such as brain-computer interfaces, neuroprosthetics, and personalized medicine. By paving the way for future investigations into brain activity decoding, our study contributes to an enhanced understanding of the human brain and its intricate functions.

Simultaneous wide-field cortical calcium imaging and behavioral recording:

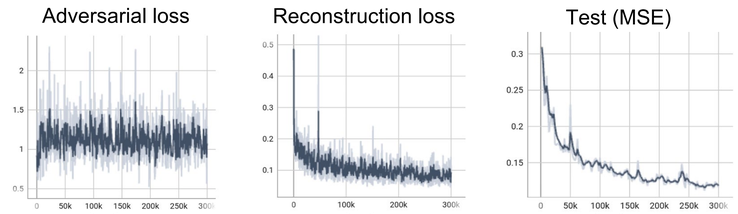


Methods:

MesoGAN model architecture.



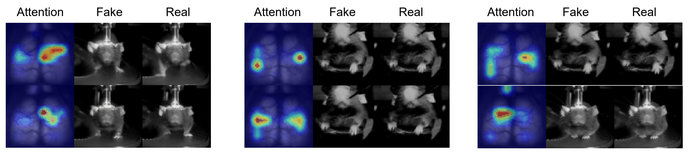
Model training:



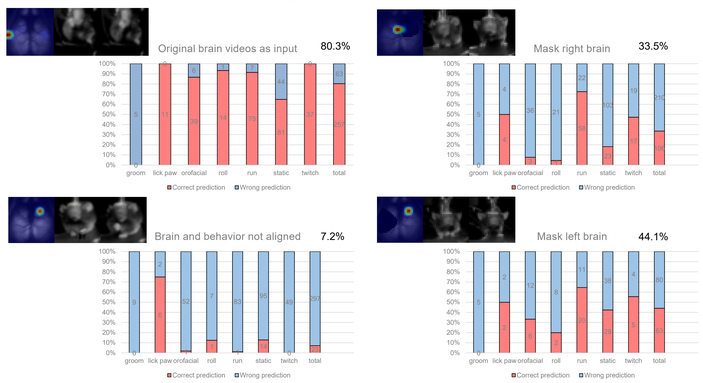
The generator and discriminator networks compete:
– Discriminator network trains to classify real vs. generated behavior videos, tries to maximize probability of real videos, minimize probability of generated videos.
– Generator network adjust parameters so generated behavior videos fool the discriminator, trains using the gradient of the discriminator network, and backpropagated through the network so samples look more like real behavior videos.

Results:

Example generated behavior videos with attention maps overlaid on the brain.

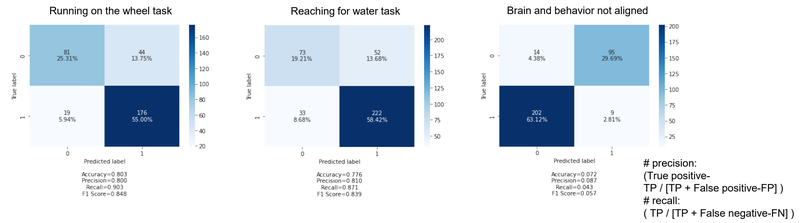


Quantification of behavioral category prediction accuracy by human raters.



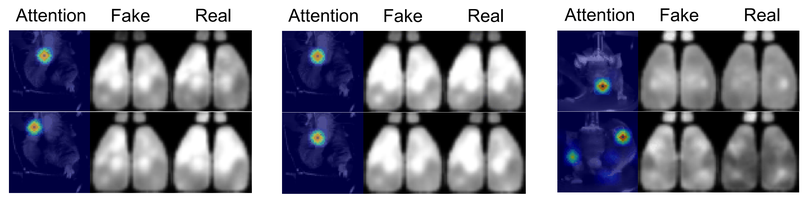
Results:

Confusion matrix of behavior prediction accuracy.

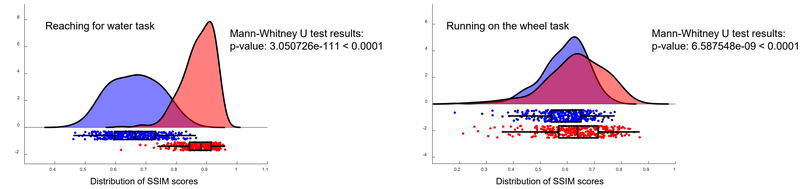


precision:
(True positive-
TP / [TP + False positive-FP])
recall:
(TP / [TP + False negative-FN])

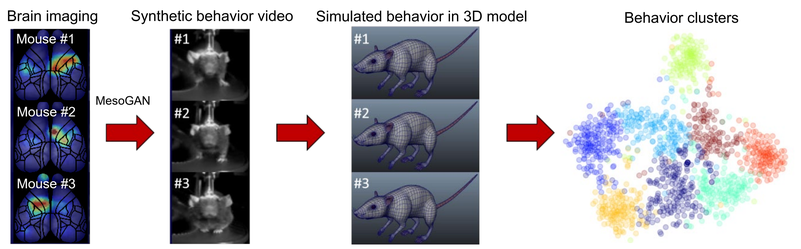
Generating wide-field brain activity from behavior video.



Quantification of generated brain videos using Structural Similarity Index (SSIM) score.



Implications for brain-computer interfaces and representing mouse brain and behavior in a Common Brain-Behavioral Framework.



Discussion & conclusion:

MesoGAN has the potential to facilitate future studies that delve deeper into the complex relationship between neural activity and behavior, ultimately paving the way for novel therapeutics.

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1. **Xiao, D.**, Forys, B.J., Vanni, M.P. et al. MesoNet allows automated scaling and segmentation of mouse mesoscale cortical maps using machine learning. **Nat Commun** 12, 5992 (2021). https://doi.org/10.1038/s41467-021-26255-2.
2. Bolaños, L.A.*, **Xiao, D.***, Ford, N.L. et al. A three-dimensional virtual mouse generates synthetic training data for behavioral analysis. **Nat Methods** 18, 378–381 (2021). https://doi.org/10.1038/s41592-021-01103-9.