Quantifying behaviors in non-human primates using deep learning

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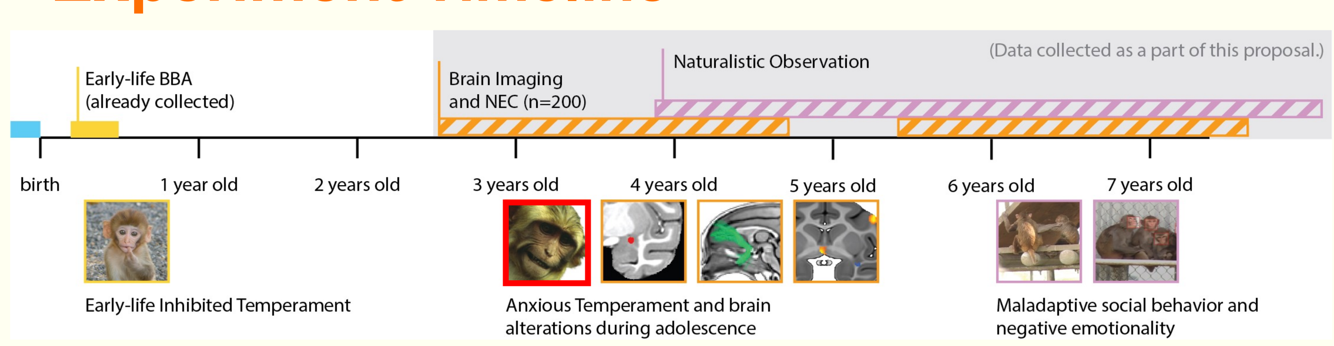
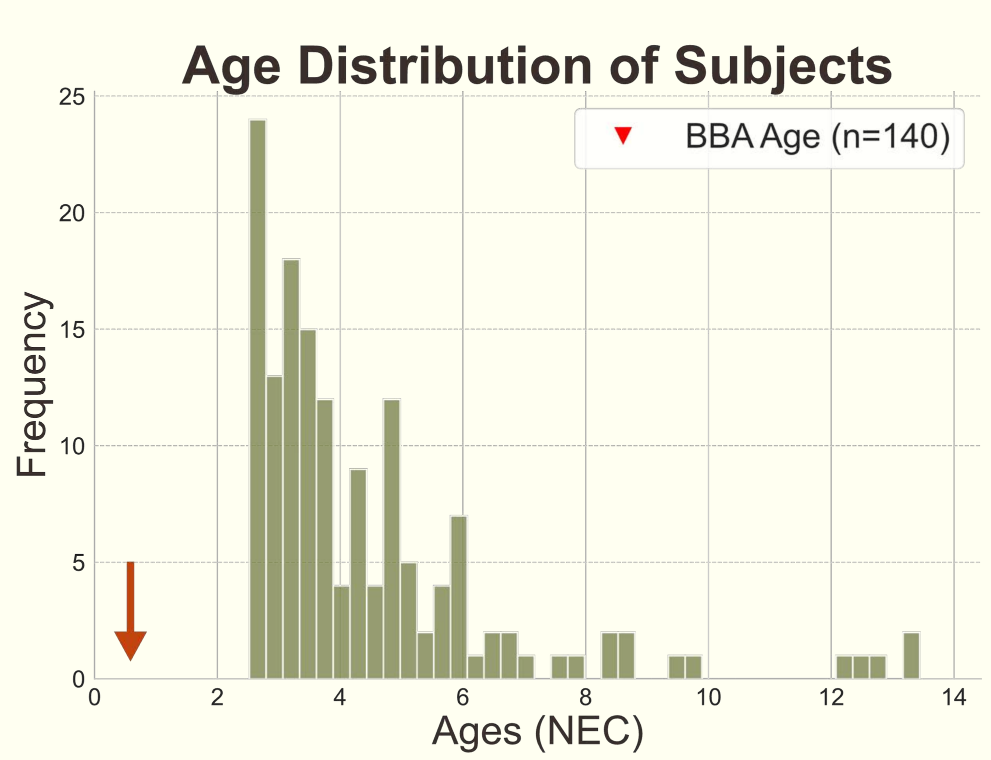
Deep learning can identify anxiogenic phenotypes in non-human primates:

- Anxiety disorders affect one in four individuals, are a risk factor for the later development of depressive disorders, and are often comorbid with other disorders
- Early-life behavioral inhibition is trait-like and a significant risk factor for the development of anxiety disorders
- The similarity between non-human primates (Macaca mulatta) and humans in brain structure and complex socio-emotional behaviors make NHPs a valuable translational model
- We utilized a well-validated NHP model and cutting-edge deep learning techniques to understand the development of behavioral inhibition from infancy to adulthood

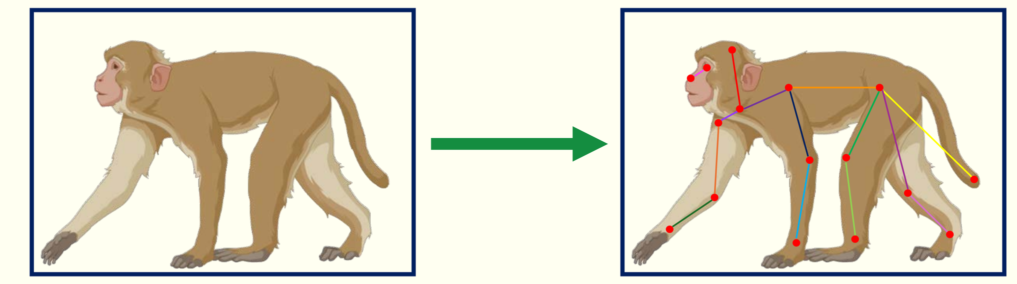
Experiment Timeline



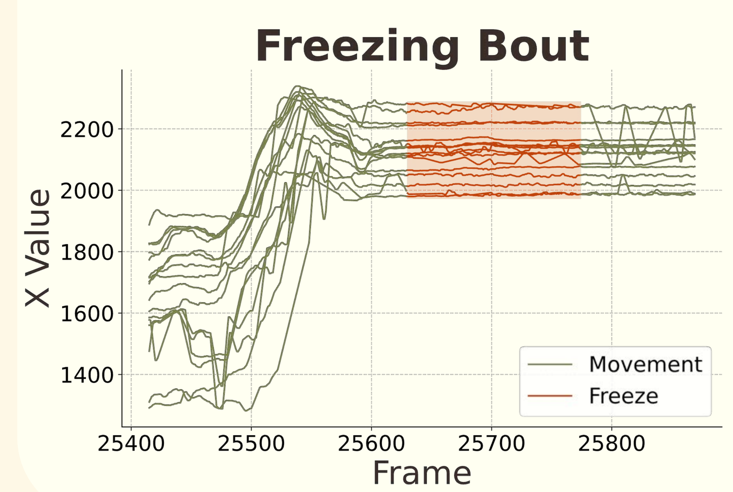
- Infant macaques were assessed for “inhibited temperament” (IT) during infancy as a part of the CNPRC BioBehavioral Assessment (BBA), based on a composite measure of various behaviors during separation from their mother
- The same animals 2.5-13 years later (median = 3.6) underwent the no-eye-contact (NEC) human intruder test followed by multimodal neuroimaging (rs-fRMI, FDG-PET, DTI)
- Here, we aim to understand how infant inhibited temperament is associated with behavioral inhibition as animals transition to adulthood

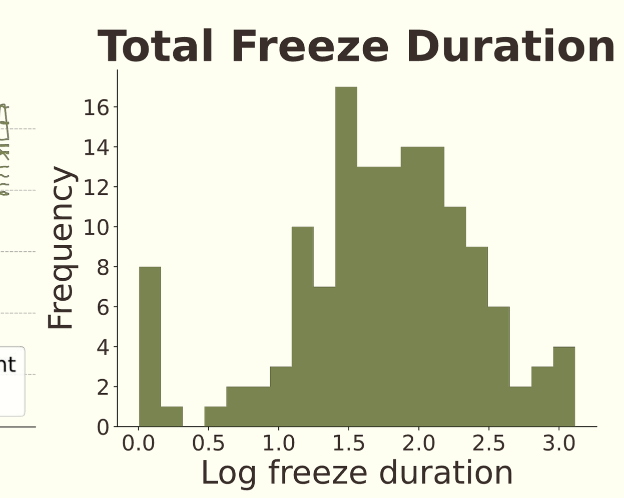


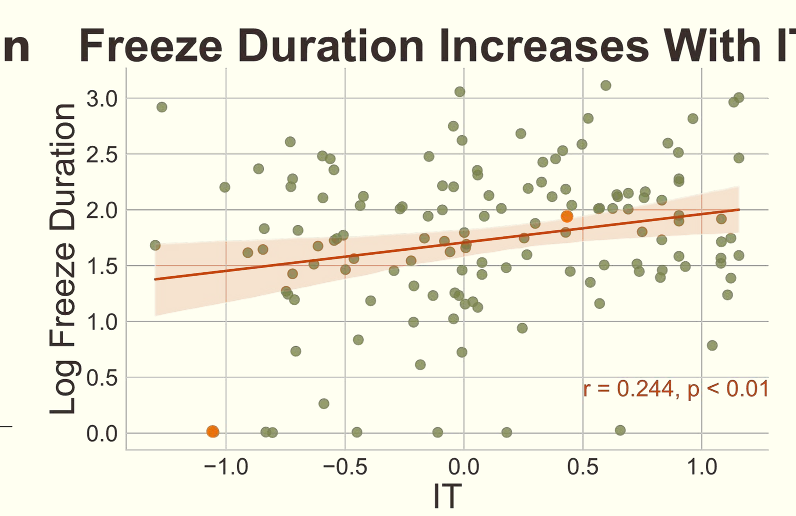
Infant IT is associated with freezing behavior during adolescents/adulthood

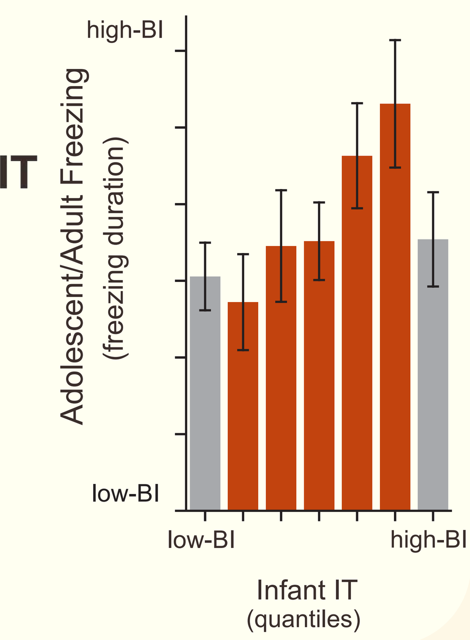


- We implemented a Mask R-CNN architecture with ResNet-50+FPN backbone for high-precision primate pose estimation and keypoint detection. Model was fine-tuned on OpenMonkeyChallenge, a public dataset containing 66,917 annotated training images of keypoints (*Yao et al., 2023, OpenMonkeyChallenge*)
- Keypoints were used to automatically quantify freezing during the NEC human intruder test



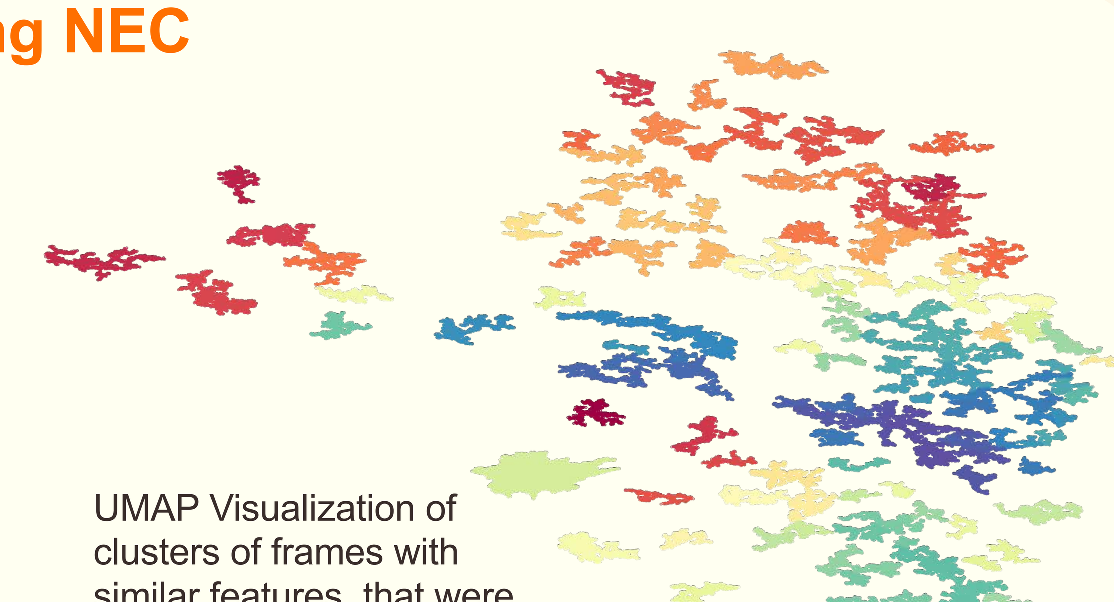






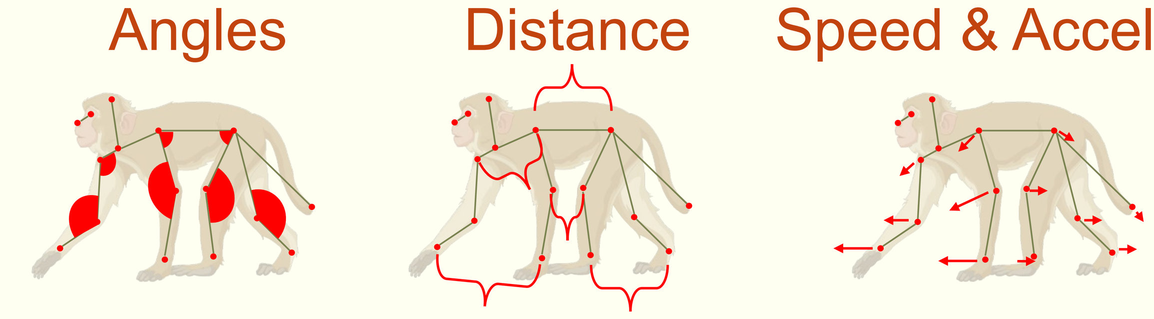
Identifying and Validating Action Motifs During NEC

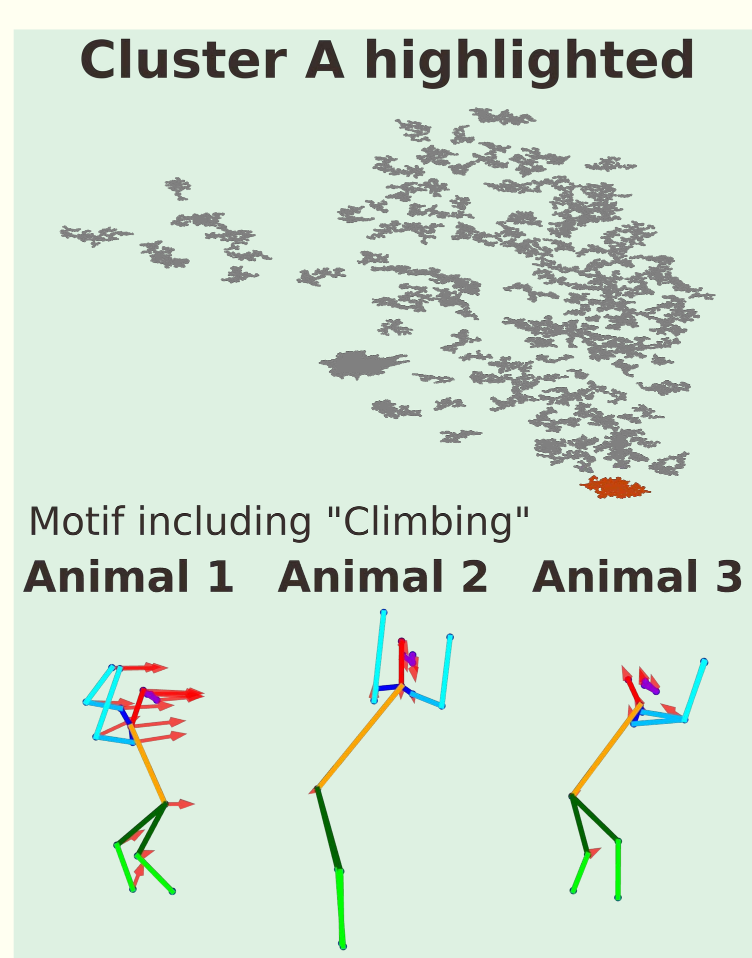
- Behavioral features were extracted from keypoints across 54,000 frames per subject (n=140), capturing spatiotemporal dynamics of movement
- Features were clustered to identify video frames with similar feature patterns.
- We can validate common features (n>50) by visually confirming the consistency of behavior.

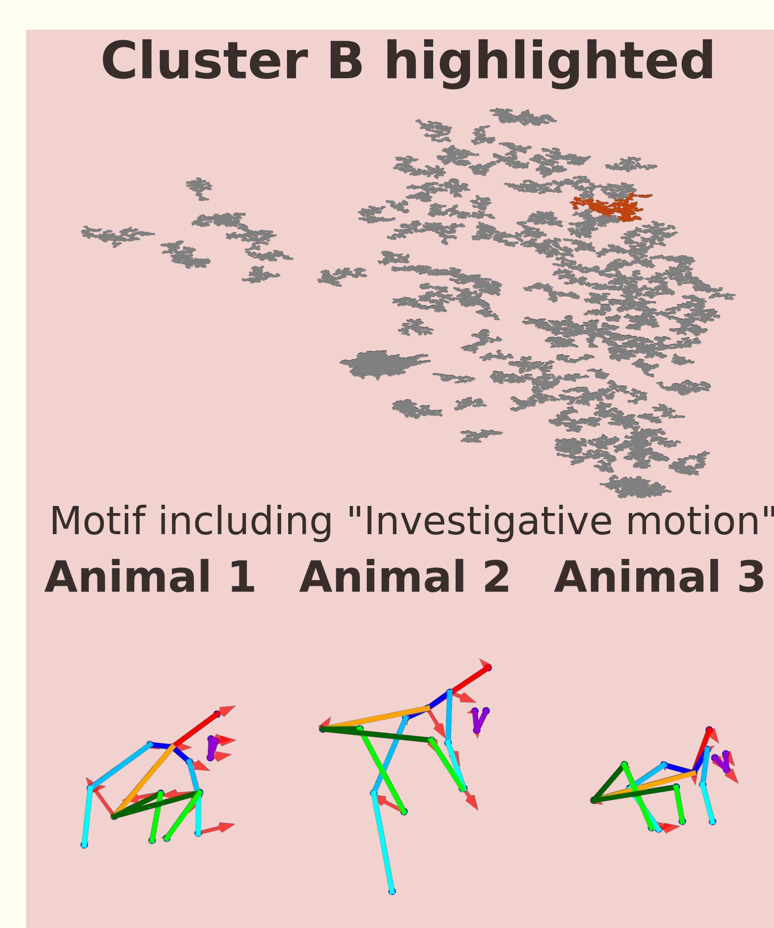


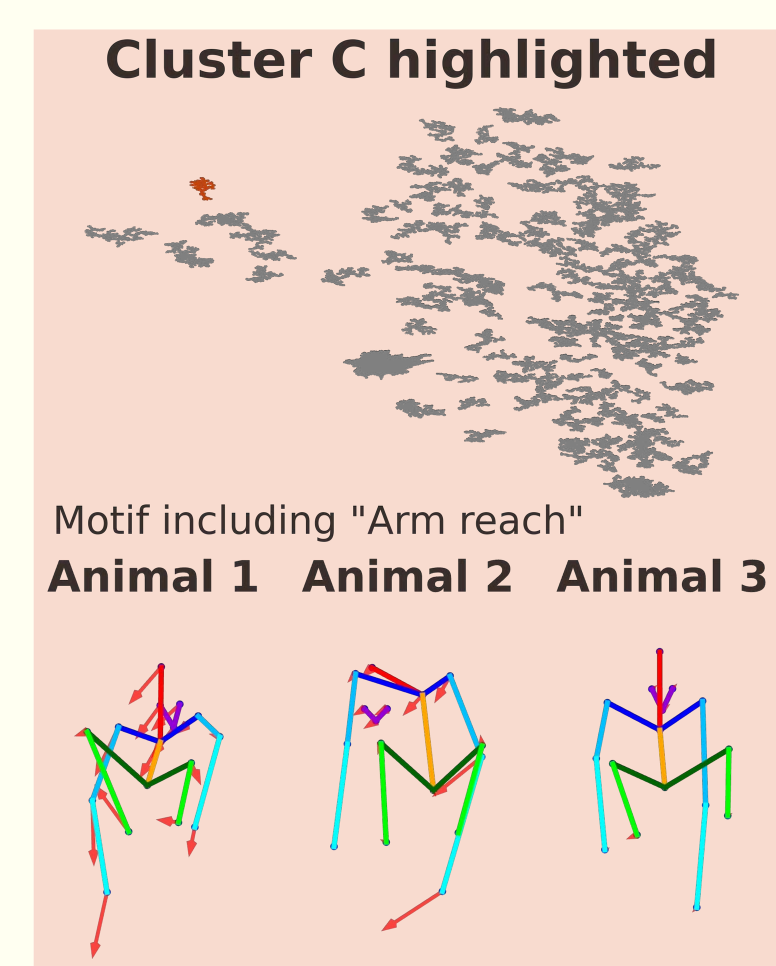
UMAP Visualization of clusters of frames with similar features, that were present in >50 animals.

Clusters based on 50 components explaining 95% of variance, UMAP visualization, and HDBSCAN clustering

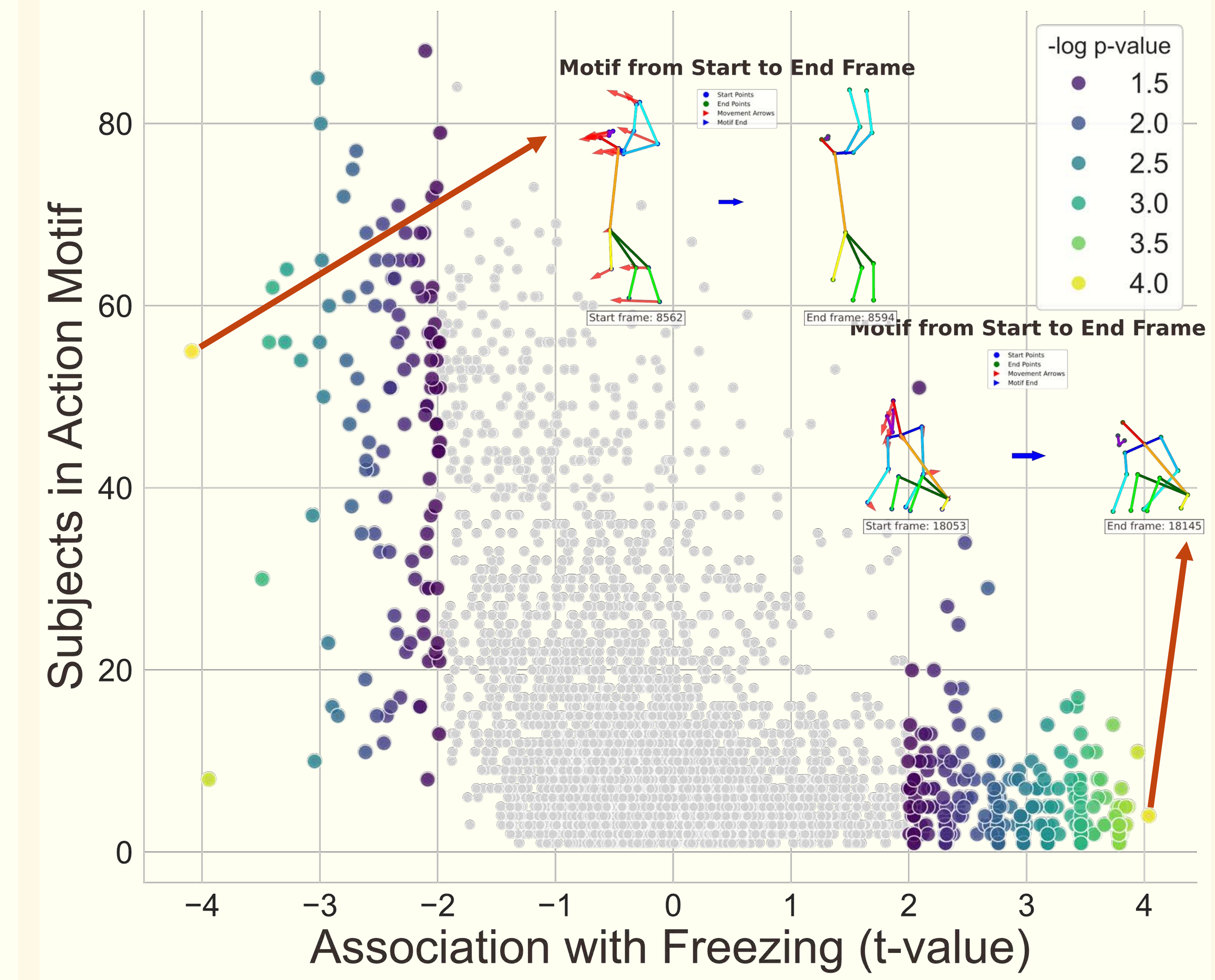






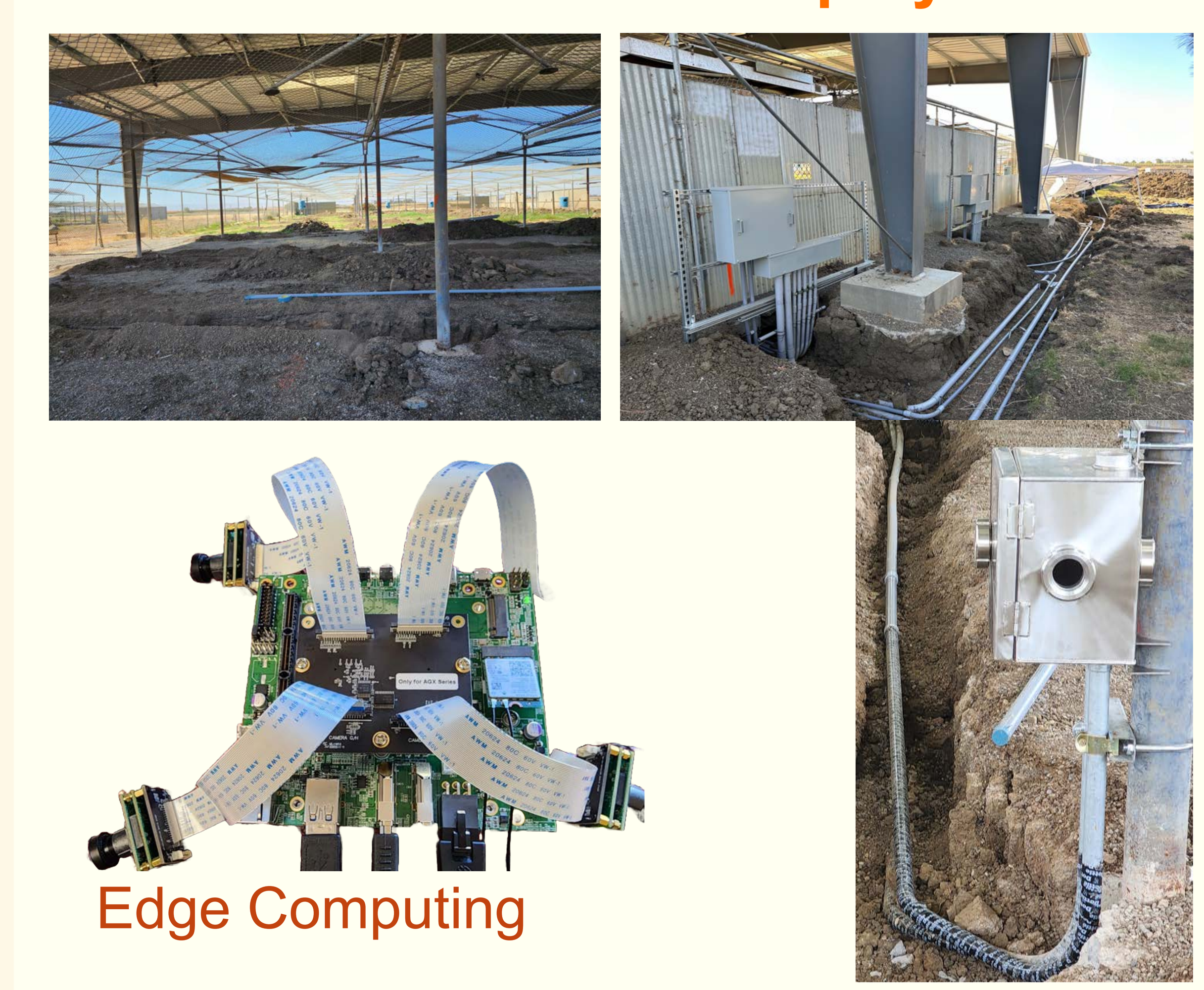


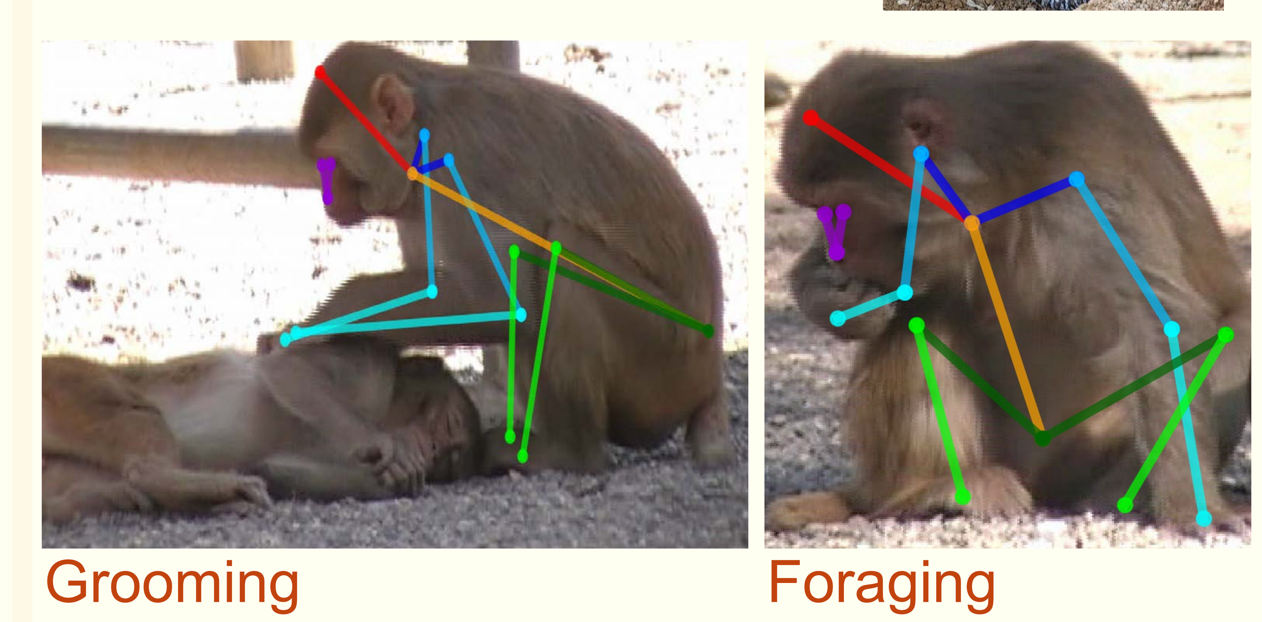
Freezing related Behavioral Motifs



Motifs correlated with freezing (p<.05)

Towards Real-World Deployment





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Machado, C.J., Bliss-Moreau, E., Platt, M., & Amaral D.G. (2011). Social and nonsocial content differentially modulates visual attention and autonomic arousal in rhesus macaques, *PLoS One*, 6(10): e26598.

Acknowledgements:

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