MouseNet Similarity to Mouse Brain with simulated mouse vision dataset and retinotopy

BME 499 Final Presentation

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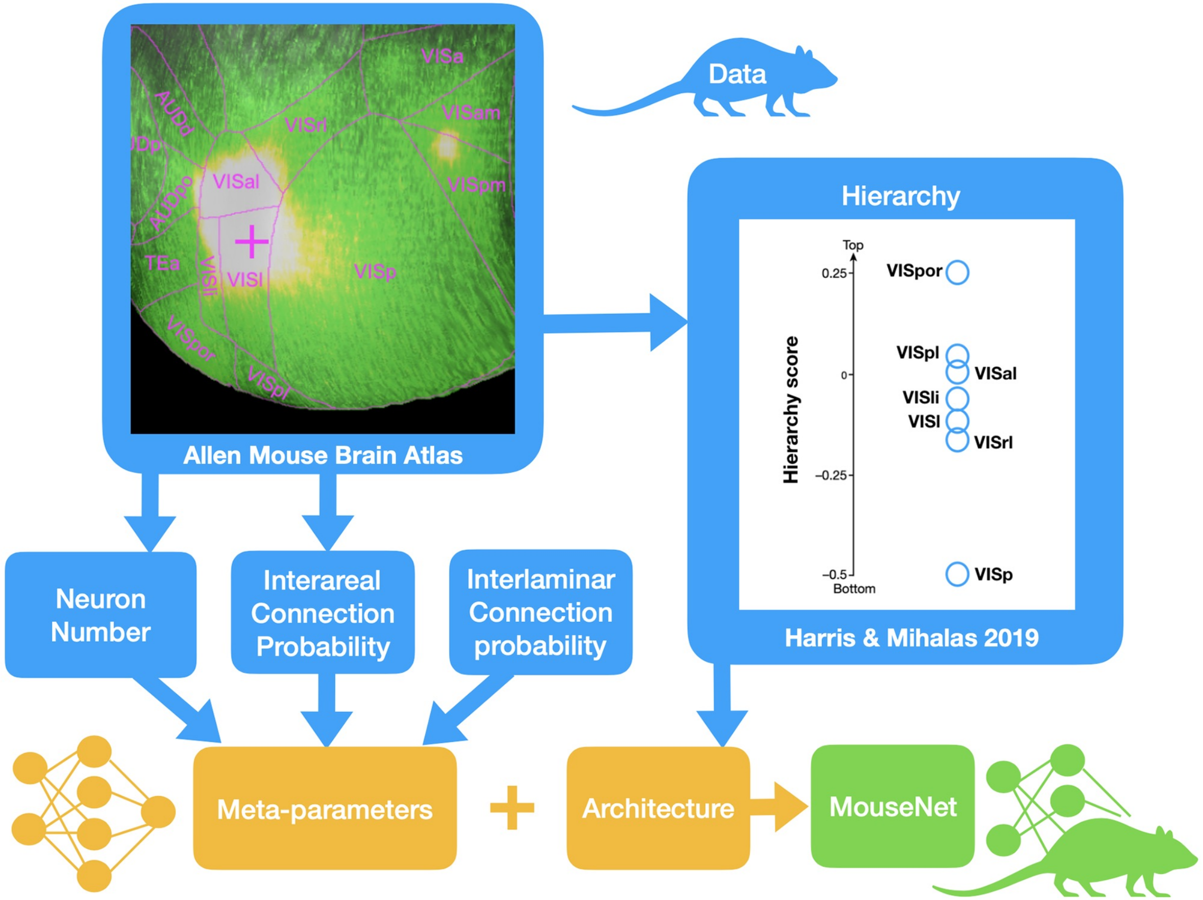
Project Background

Modelling Mouse Visual Cortex: MouseNet

- CNN architecture inspired from neural architecture of visual system in primates [1].
- Mice architecture shallower than primates [1].
- To better understand mouse brain architecture →MouseNet, Biologically constrained neural network [1].

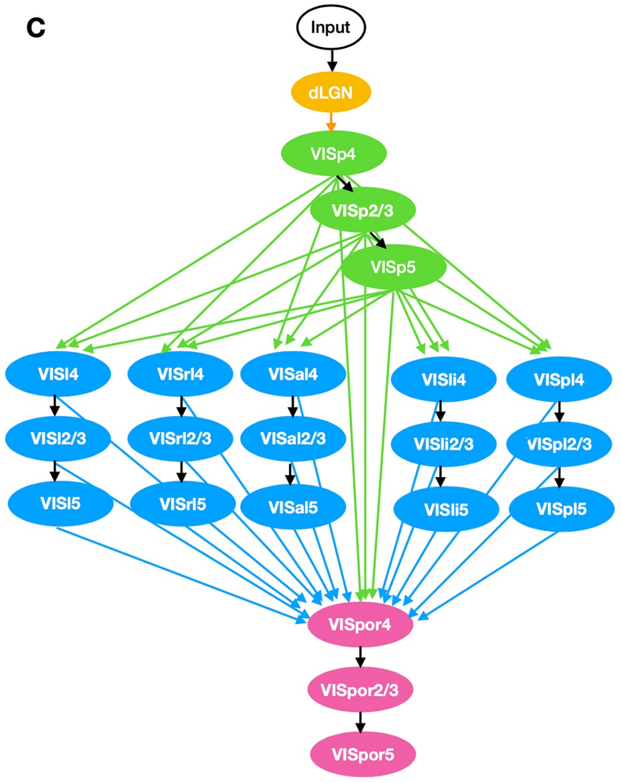


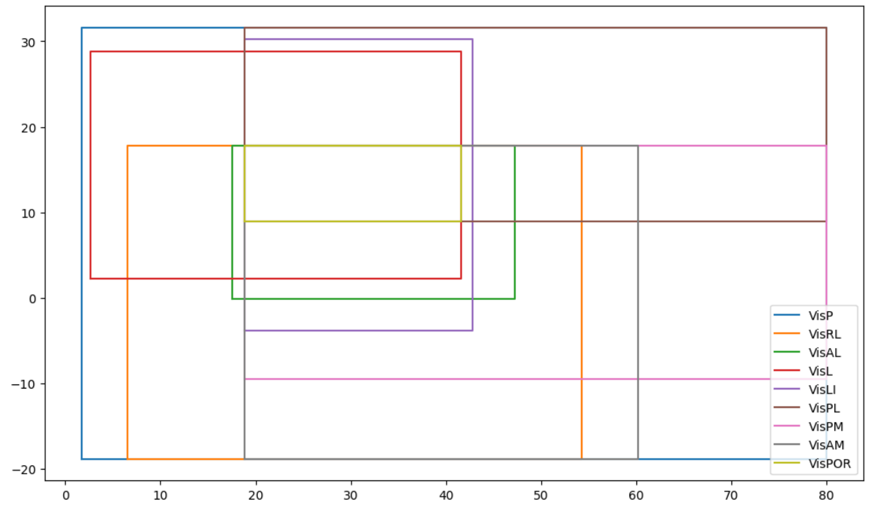
Research Scope

- Impact of training on similarity with brain: training performance does not necessarily correlate with improvements on similarity with brain.
- My research: investigate the impacts to similarity between MouseNet and mouse brain after changes:
  - 1) Network design: retinotopic mapping of neurons within visual cortex
  - 2) Training task and input: with realistic mouse vision data and prediction task.
- Goal and Impacts:
  - Improve the MouseNet architecture to be more realistic to mouse cortex
  - Assess the MouseNet model after making the modelling process closer to biology → contributes to computational neuroscience modelling research.

Retinotopic mapping

- Original MouseNet: approximate input passing and propagation.
- Retinotopic mapping: mapping of retina to neurons within different areas in the visual stream [2].
- → allows different areas of previous layer output to be used for downstream layers according to retinotopy.

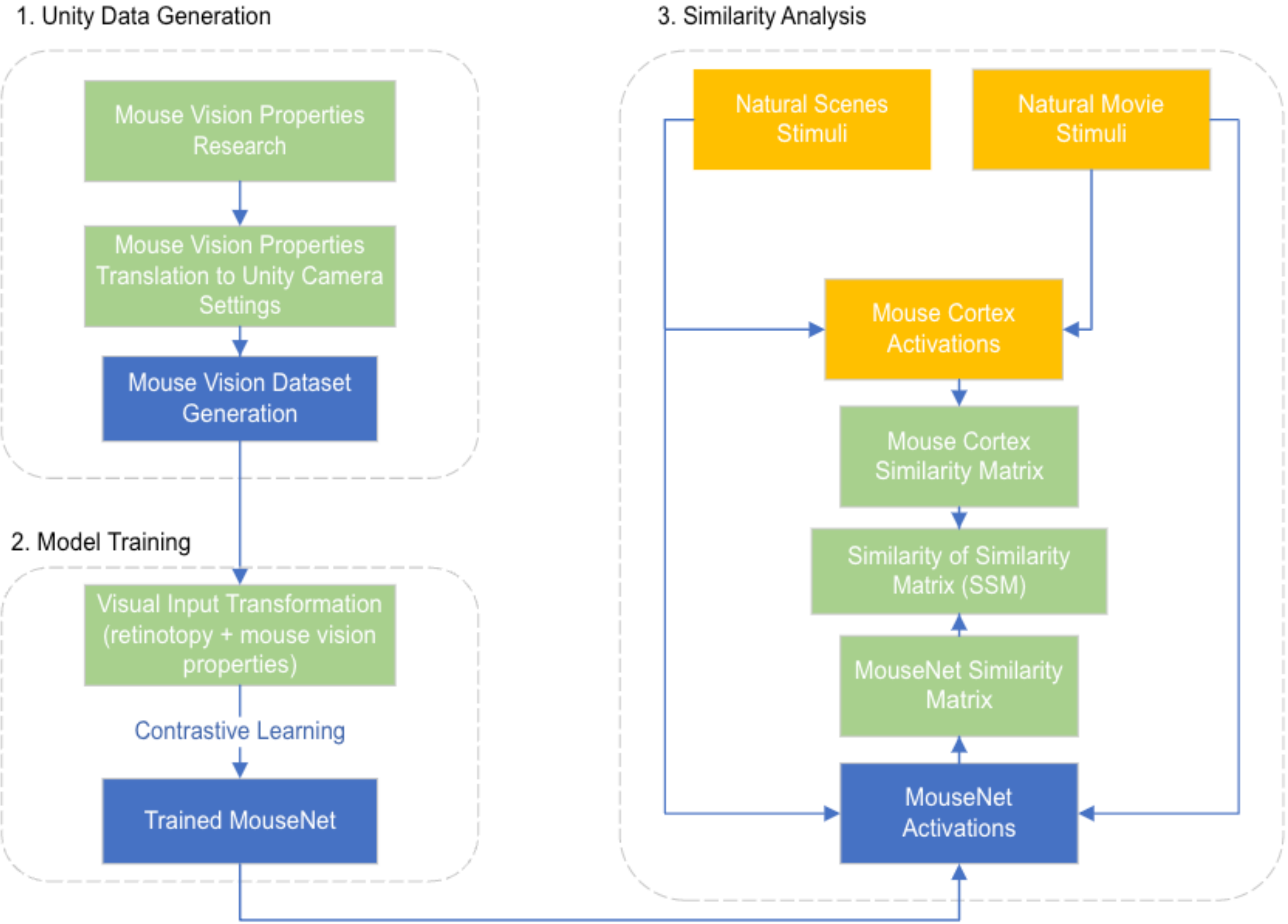




Mouse Vision Data

- Original MouseNet: trained with ImageNet dataset.
- Training task: image classification
  - image not visually close to mouse vision (blurring, angle etc. not close to mouse)
  - image classification may not be appropriate for describing the functions of mouse visual cortex.
- → construct videos simulating mouse vision

Project Workflow



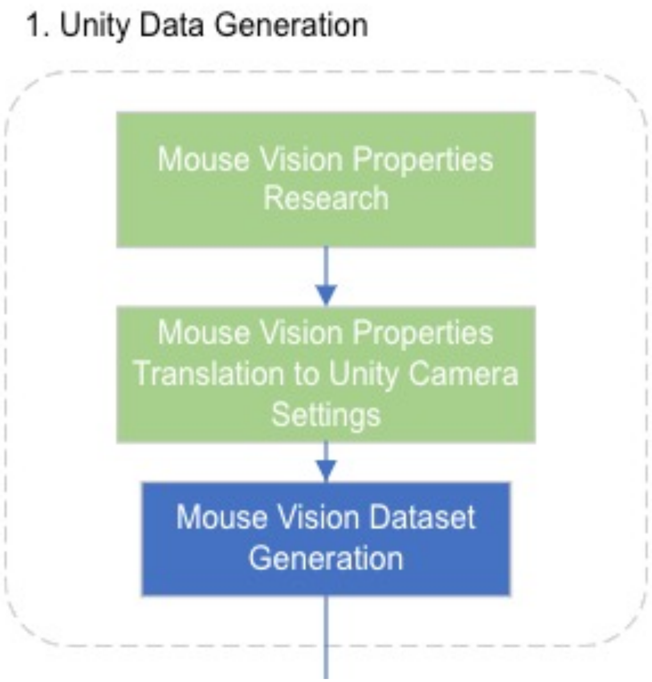
1. Constructing Biologically Realistic Mouse Vision Dataset

Unity Meadow Field Simulation

- Cameras located on left and right eyes of the mouse.
- Mouse simulated to run in meadow field with random path and head motions.

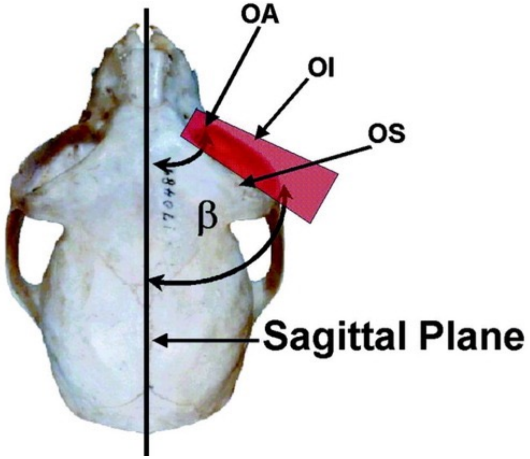
Mouse Vision Properties

- Adjust camera settings based on mouse vision properties.
- Mouse Vision Properties gathered from research:
  - Eye orientation, interocular distance
  - Angle of convergence
  - Focal Length/Field of view
- Determines camera settings located on the mouse eyes.
  - Position of camera on eye, orientation and rotation.
  - Focal length settings and recording resolution.

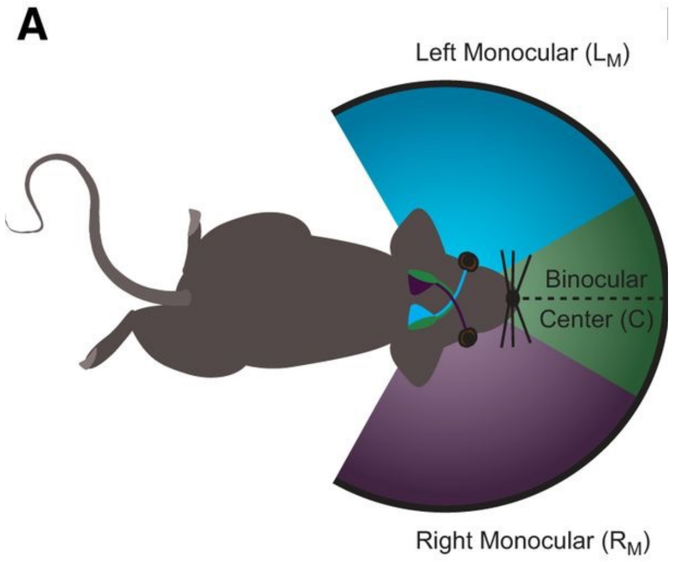


Results: Camera Settings

	Interocular Distance [3]	Orbit of Convergence [4]	Upward Tilt [5]	Focal Length [6, 7]	Visual Acuity [1]
Mouse Vision	1cm	38.6 degrees	6 degrees	2.6mm,	0.5 cycles/degree
Camera Settings	+/- 0.5cm Z-axis translation	+/- 38.6 deg Y-axis rotation	+6 deg Z-axis rotation	2.6mm focal length and 140 deg monocular field of view (vertical and horizontal)	2 pixels/cycle x 0.5 cycles/degree = 1.0 pixel/degree. 140x140px resolution



Orbit of convergence angle

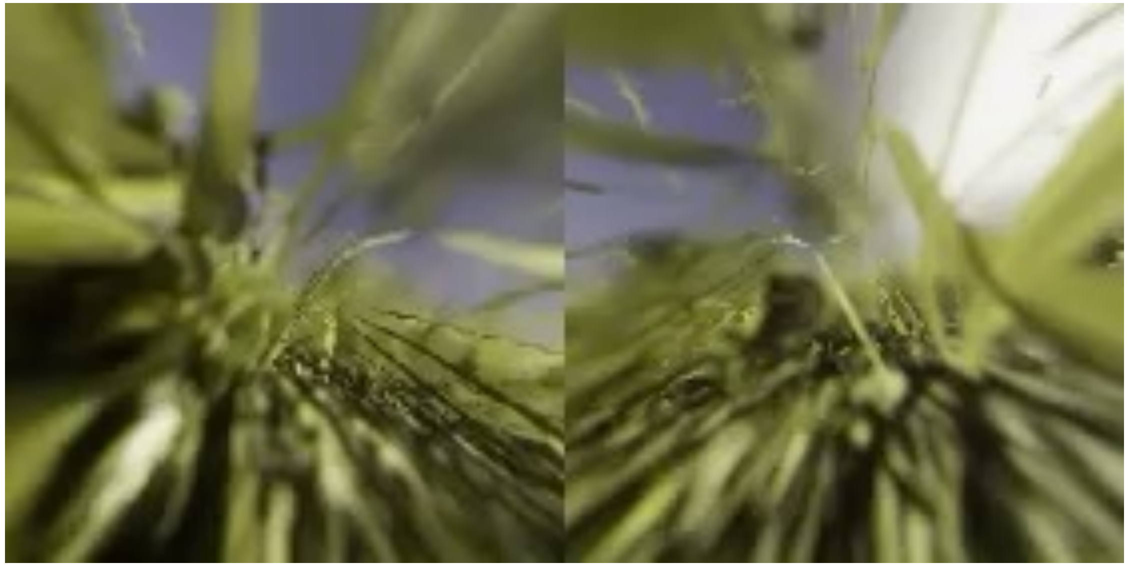


Field of View (FOV)

Results: Generated Videos Using Unity

High Resolution (as example)

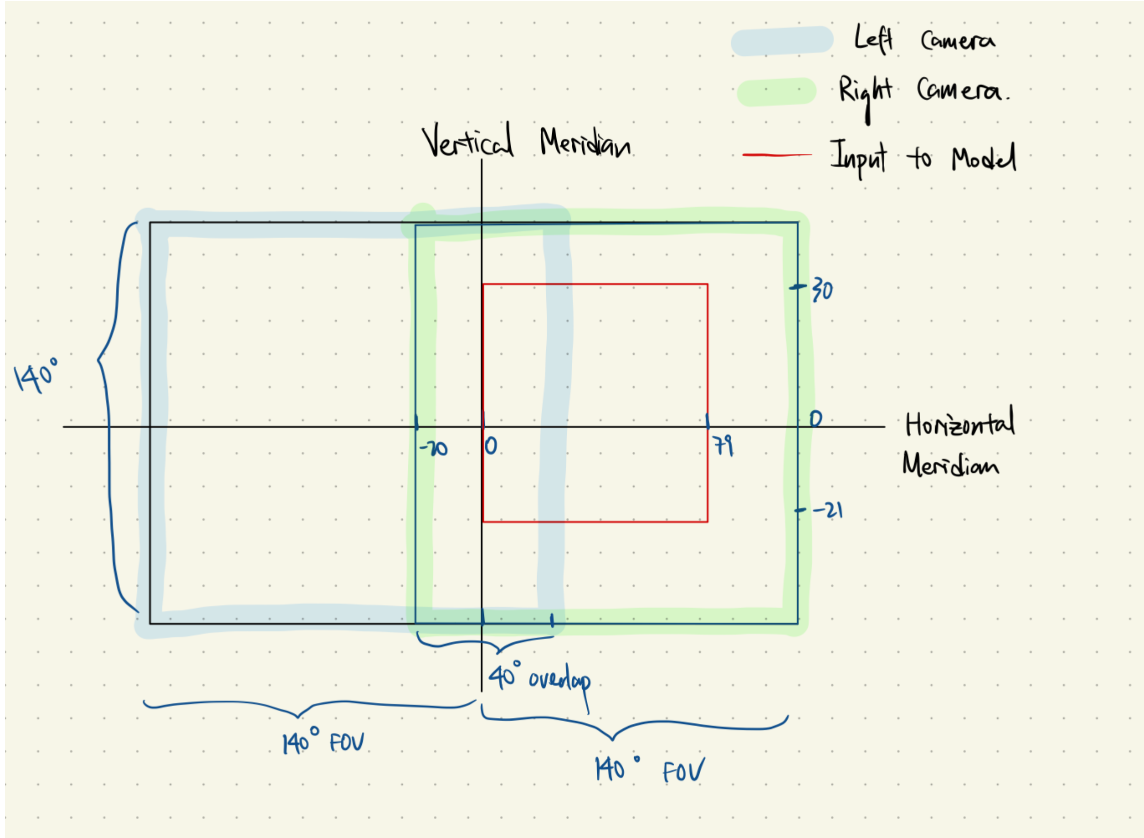
Mouse Eye Resolution (final results)

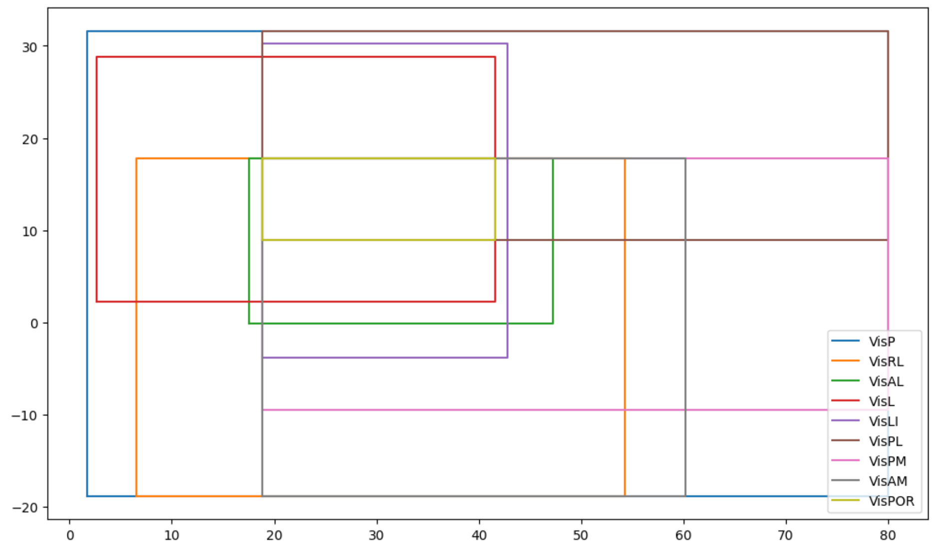


2. Training Modified MouseNet

Input to Model Training

- VISp included representation of the right visual hemifield between ~0 (from the vertical meridian) and 90° field of view and ~25–35° above and below the horizontal meridian [2].
- There are around 40 degree overlap between left and right visual field [4].

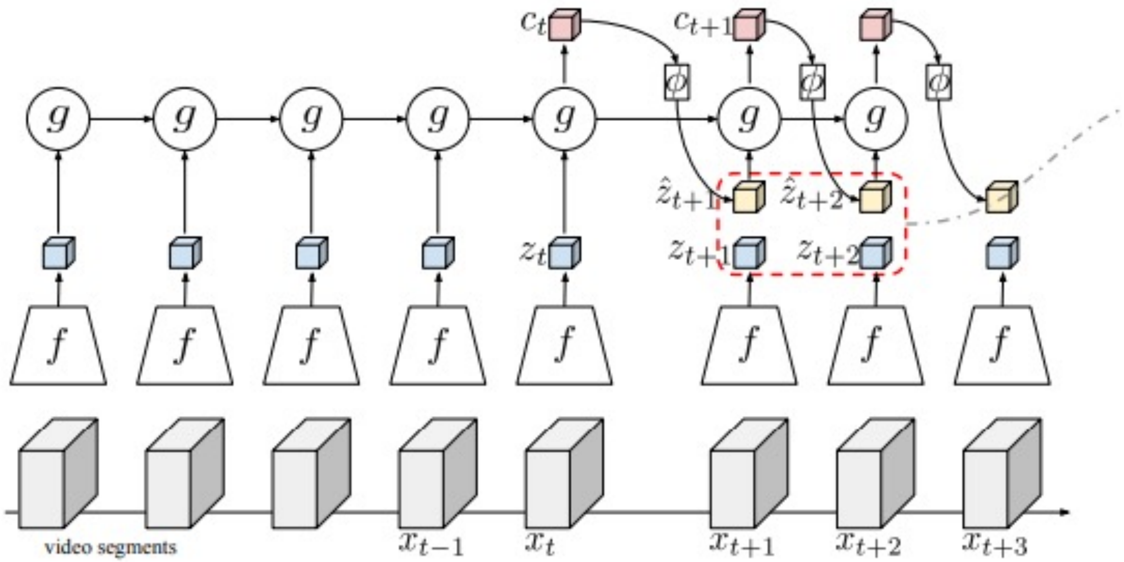




Training Setup

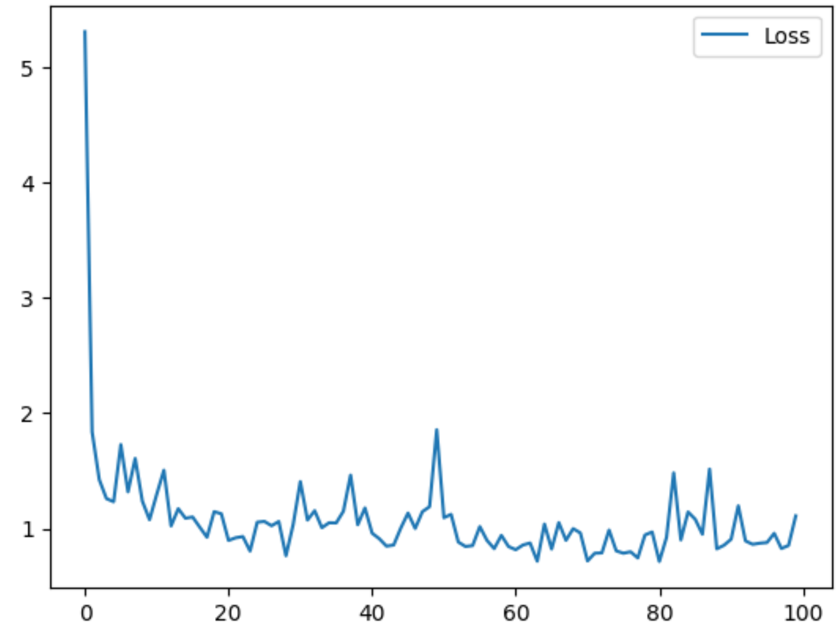
- Dense Predictive Coding framework (DPC): trained to predict future frames of the video, by comparing predictions with correct future states.

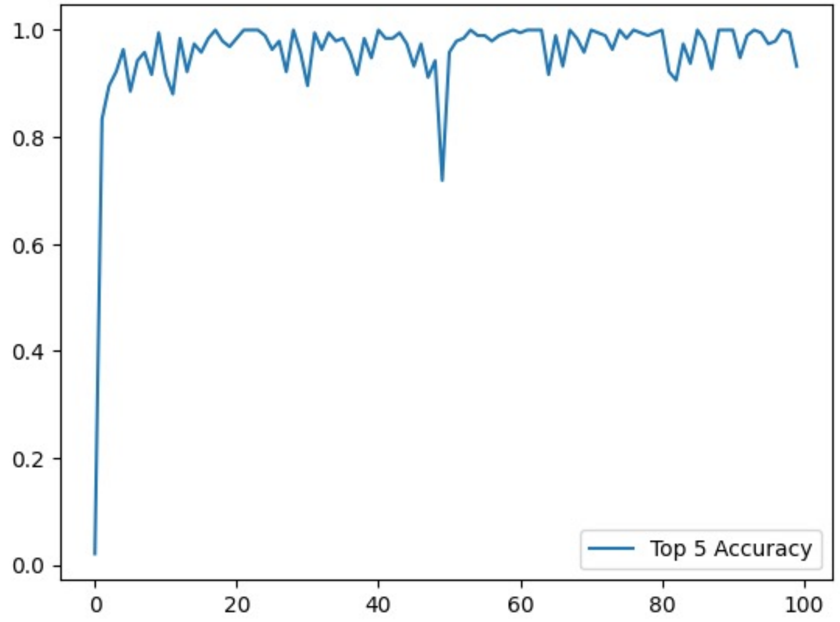
1. Get features from 5 frames of input video block.
2. Predict future frames (multiple steps into future) from features.
3. Learns contrastive loss comparing predicted frames and ground truth frames.



Results: Trained Model

- Training settings:
  - 100 epochs, Adam optimizer
  - Input: 8 Unity videos recorded at 30 frames per second, 15min each.
    - Using right eye video only.
  - Total training data frames: 216,000
  - Model checkpoint saved after each training epoch.

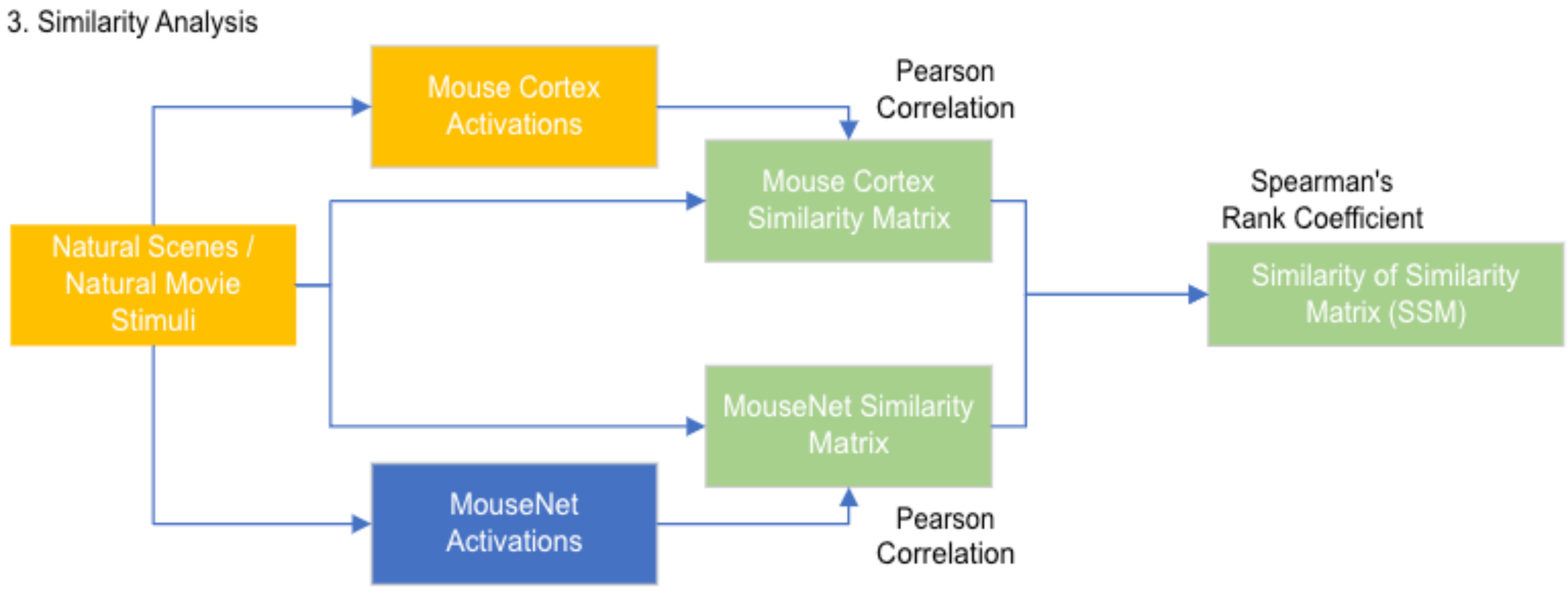




3. Similarity Analysis Between MouseNet and Mouse Brain

Representational Similarity Analysis and Similarity of Similarity Matrix (SSM)

- Similarity matrix (SM): similarity between group of stimuli vs. group of representations of these stimuli in brain/MouseNet [1].
- Similarity of Similarity Matrix (SSM): similarity between mouse cortex SM and MouseNet SM [1].



Brain vs. MouseNet Representations of stimuli

- Allen Brain Observatory dataset [8]
  - Contains experimental neuron activation data from showing different stimuli to mouse.
- Stimuli Types:
  - Natural Scenes
  - Natural Movie
- Stimuli passed to MouseNet:
  - Rescaled to 140x140
  - Same cropping as training
- Focus on activation data from 2/3 cortical layers.

scene 4

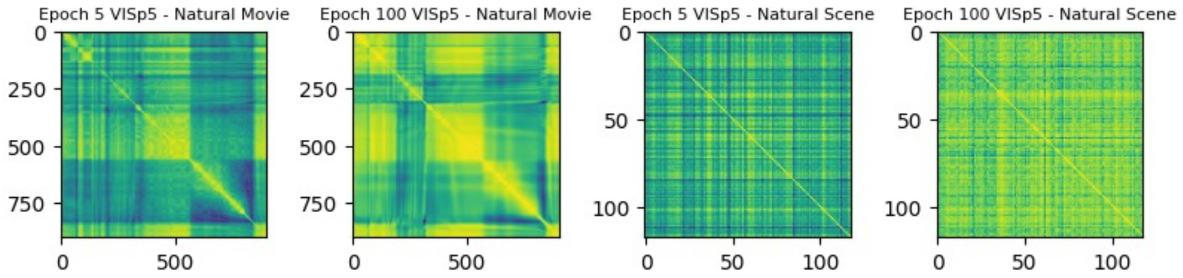
scene 83

frame 0

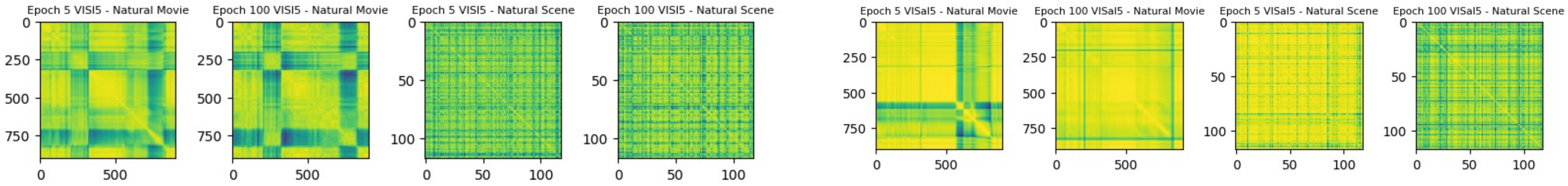
frame 400

Similarity Matrix (SM) - MouseNet

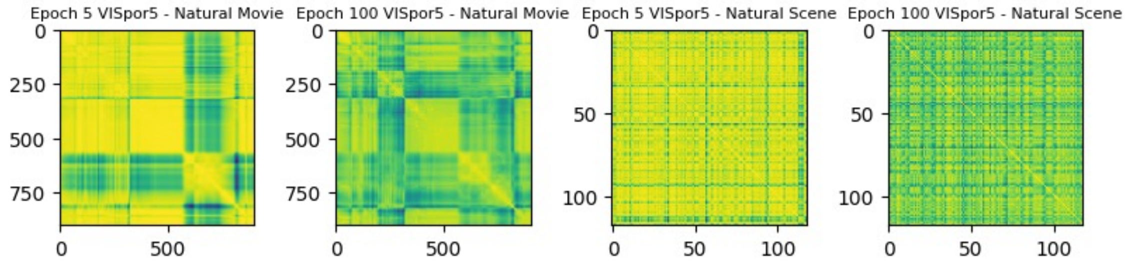
Primary Layer



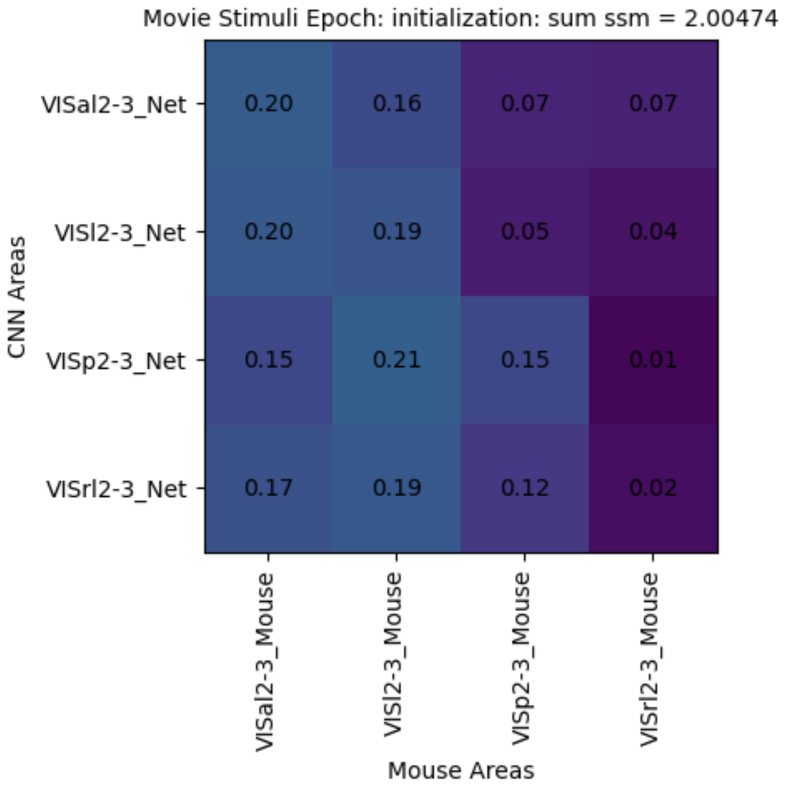
Secondary Layers

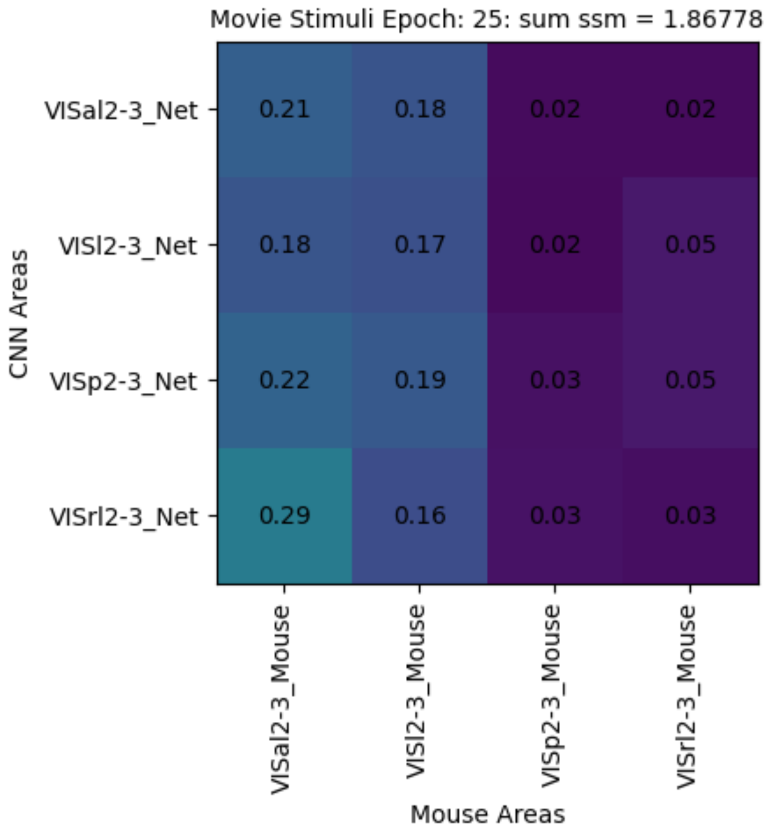


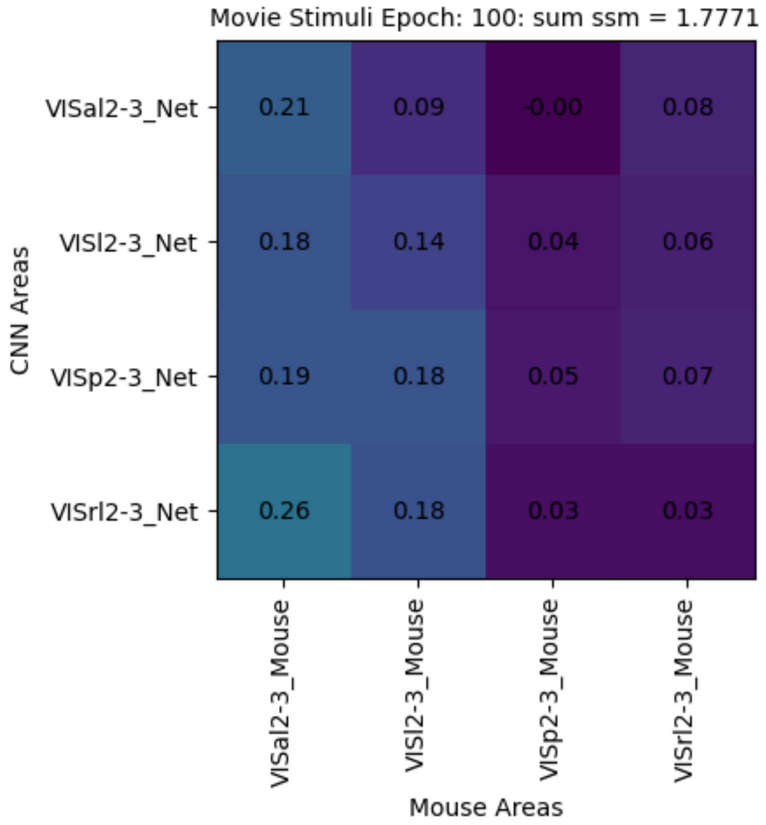
Final Layer



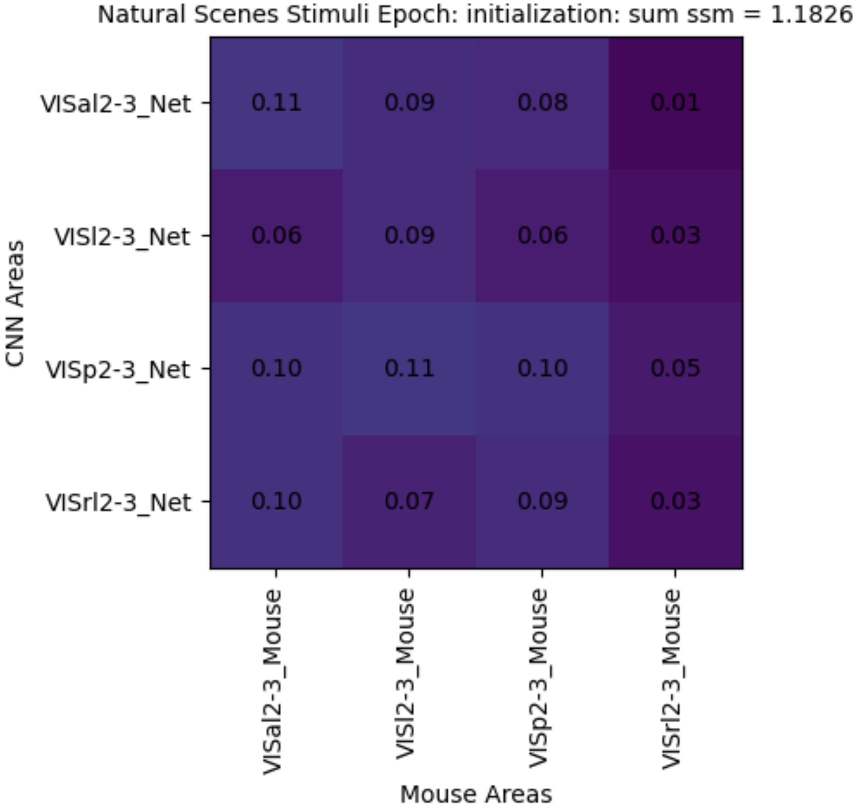
Mouse Brain vs. MouseNet SSM – Movie Stimuli

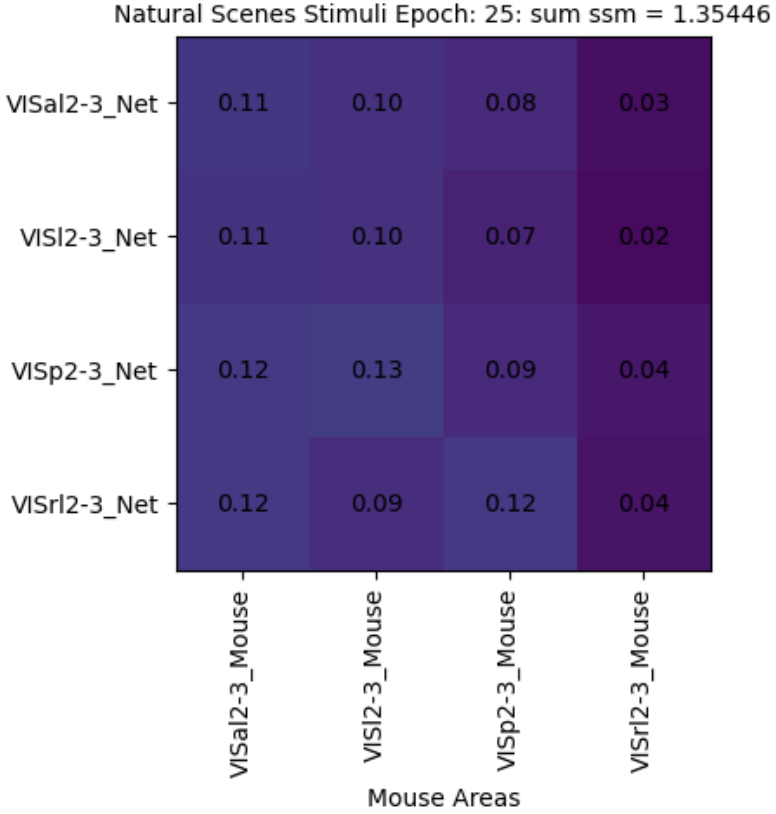


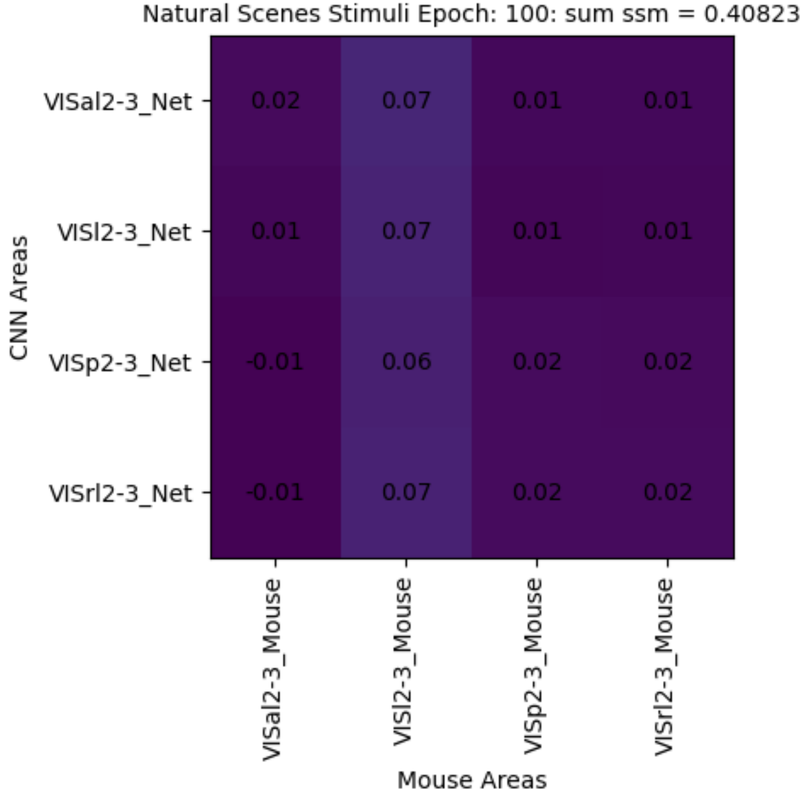




Mouse Brain vs. MouseNet SSM – Natural Scenes Stimuli

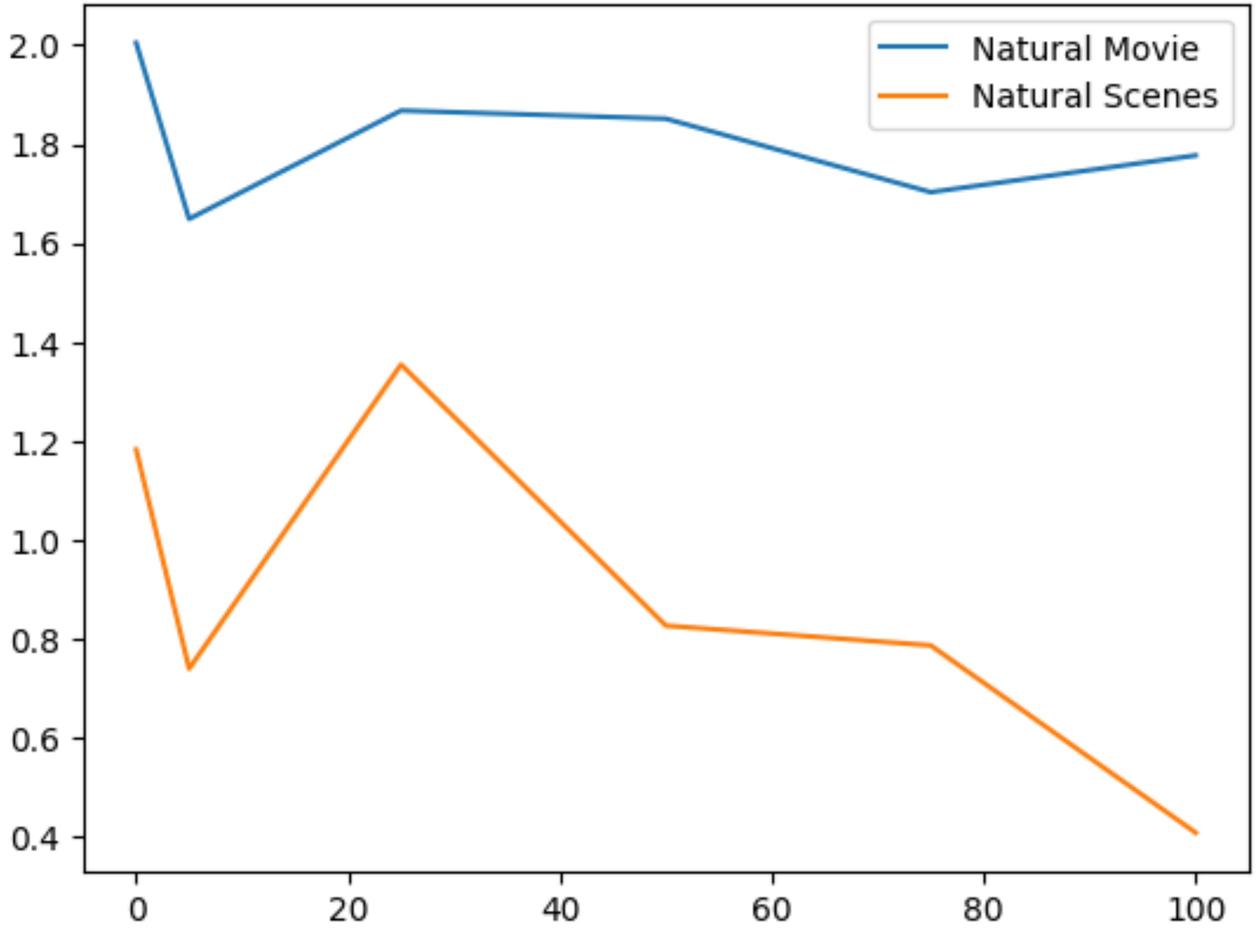






Change in SSM Sum over training epoch

- Sums of SSM for model trained at epoch 0 (initialization), 5, 25, 50, 75, 100 are calculated.
- Highest SSM sum observed at epoch 25 for natural scene.
- → training did not improve similarity.



Summary of Results and Conclusions

- Task Training does not necessarily improve similarity with brain.
  - Training MouseNet with retinotopic mapping using video inputs using prediction framework did not improve similarity based on current analysis.
  - More analysis is needed to make a conclusion on particular impacts of retinotopic mapping: compare the current results with paper results to get a better conclusion on the impact of these 2 changes.

Limitations and Future Work

- Dataset:
  - Present of unknown artefacts on the camera. Less on the trained right eye camera but impact is unknown.
  - Variation in scenes: differences in scenes may not be sufficient to train a model that encodes different natural scenes well.
- Analysis:
  - Did not use all available mouse brain data due to time and resource constraints. Analysis only contains some areas of brain vs. MouseNet. → lacks comparison with original MouseNet SSM due to difference in brain data used.
  - SSM analysis was simplified comparing with original paper: Comparison of the performance with a previously trained network without retinotopic changes not available (lack of noise-ceiling calculations)

References

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[3] J. M. Samonds, V. Choi, and N. J. Priebe, “Mice Discriminate Stereoscopic Surfaces Without Fixating in Depth,” The Journal of Neuroscience, vol. 39, no. 41, pp. 8024–8037, Aug. 2019, doi: https://doi.org/10.1523/jneurosci.0895-19.2019.

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[8] “Visual Coding Overview,” Brain-map.org, 2023. https://observatory.brain-map.org/visualcoding/ (accessed Apr. 18, 2023).