Decoding pupil area changes from V1 neuron population activity

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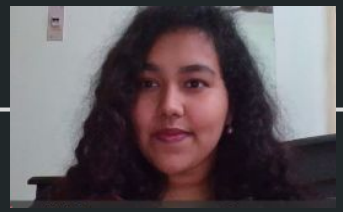
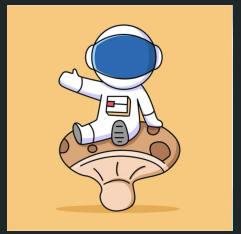
Loving Agapanthus/ Visionauts

neuromatch academy







Motivation

- Visual stimuli are processed in the visual cortex
- Spontaneous activity *in absence of* visual stimuli suggests secondary functions and beyond
- Finding a predictive relationship between pupil size and V1 activity may help piece together these secondary networks

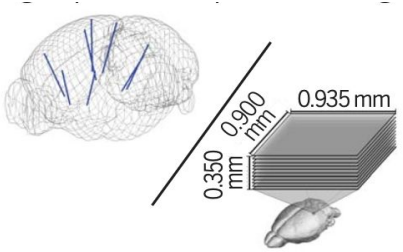
Main Objective

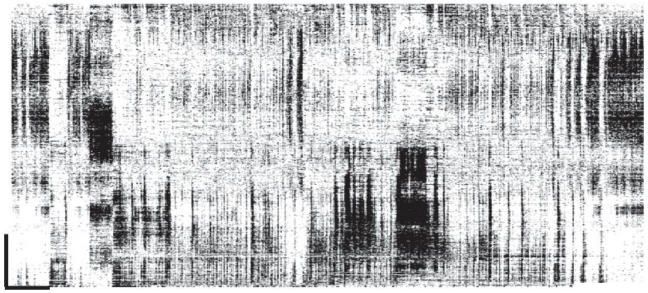
1. Predict the pupil area changes over time from the neural activity obtained from a V1 neuronal population from a mouse in a dark environment

2. Evaluate different linear and non-linear decoder models for accuracy

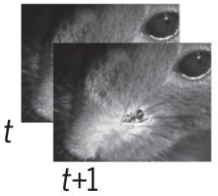
Stringer Dataset - What do we have?

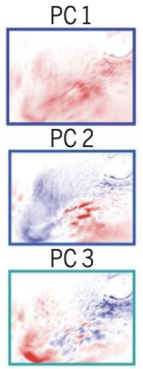
1. Recording of ~**12000 neurons** within visual cortex (calcium imaging)



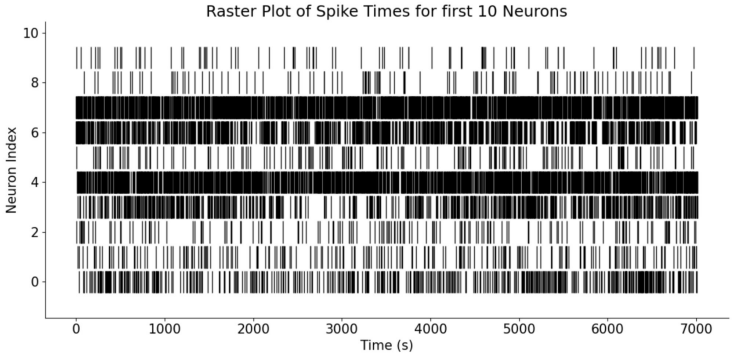


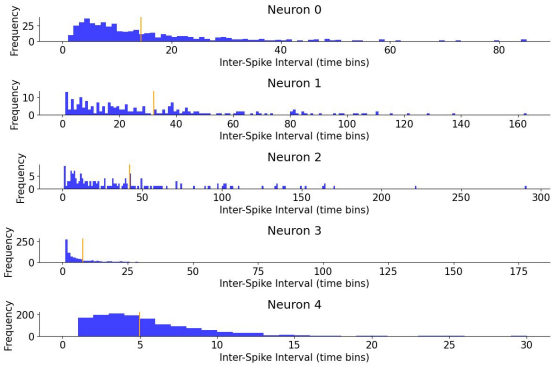
2. Behavioral Measures:
   - **Pupil size** (area + center of mass (x,y) per time bin)
   - **Running speed** of the mouse
   - **Facial movements** (behavioral components reduced from mouse's face images)

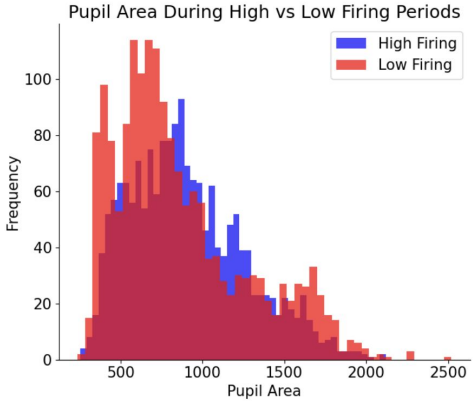


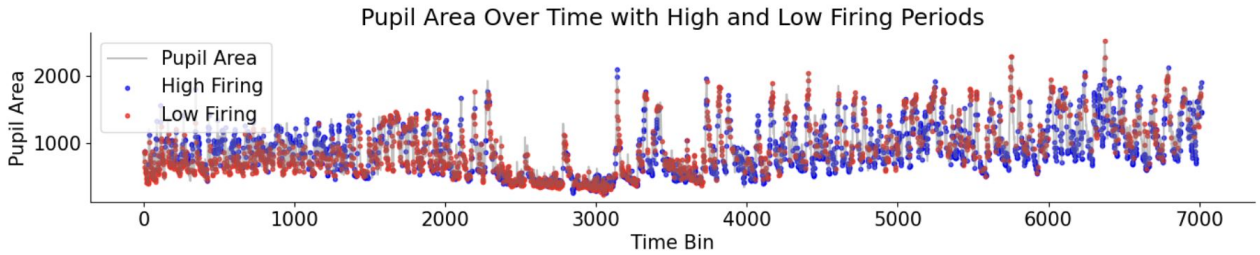


Exploratory Data Analysis

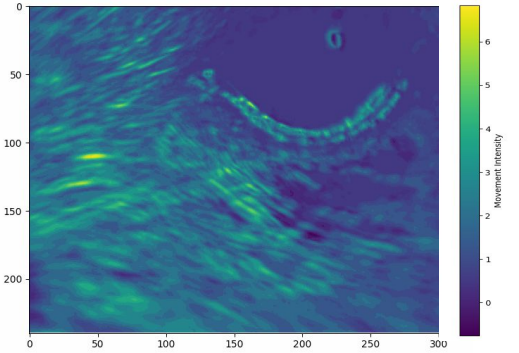




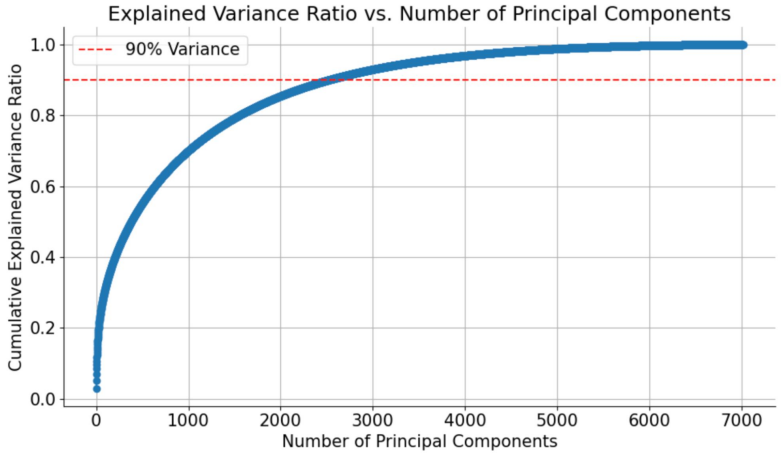




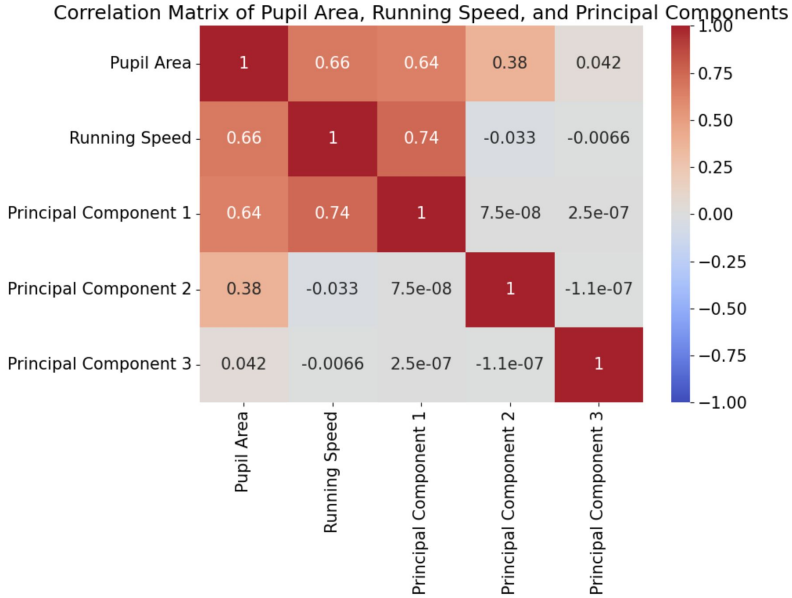
SVD reconstruction



Exploratory Data analysis — PCA



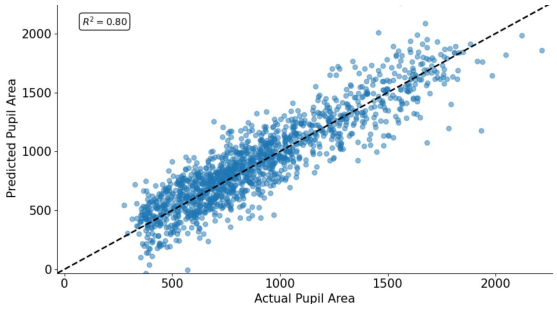
Number of principal components to explain at least **90%** variance: **2526**



Exploring the Potential Connection - Model Fitting

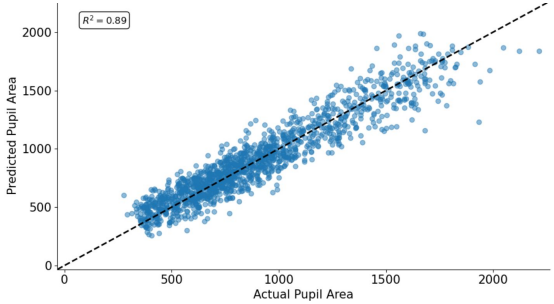
I - Linear Models

1. Ridge Regression



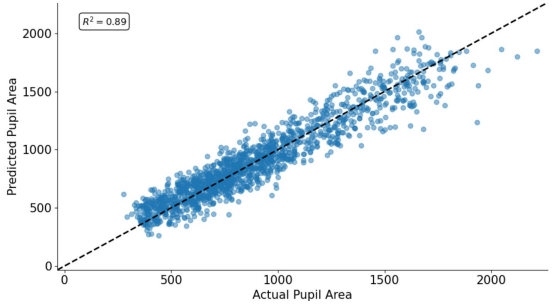
R^2 Score: 0.80
Best Alpha: 1000000.0

2. Lasso Regression



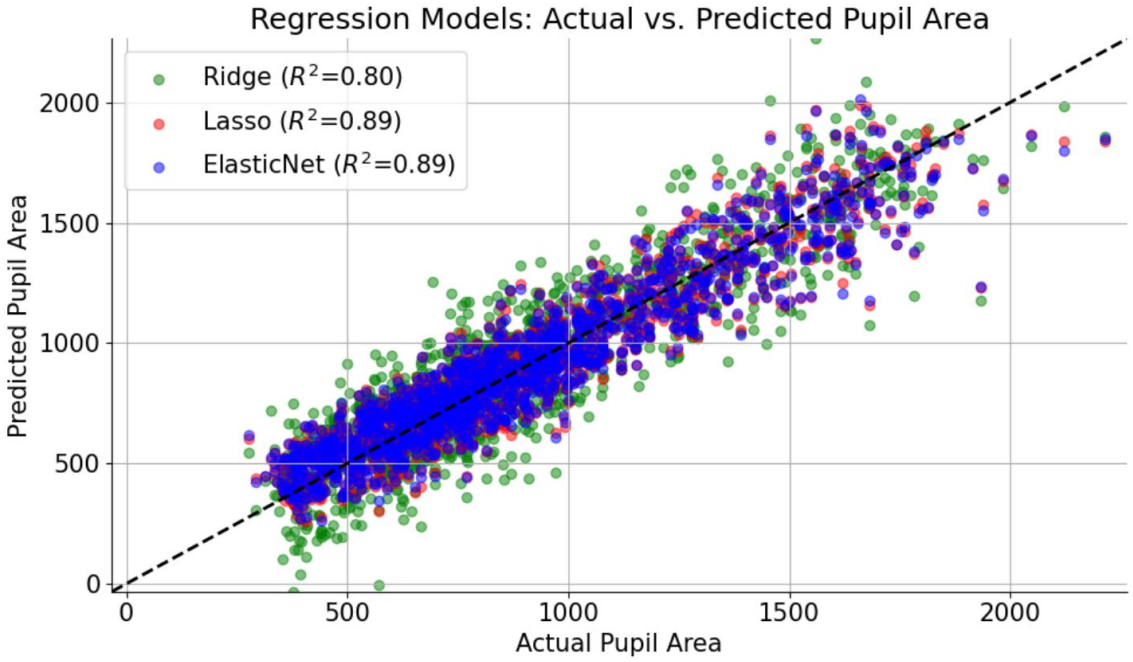
R^2 Score: 0.89
Best Alpha: 100.0

3. ElasticNet



R^2 Score: 0.89
Best Alpha: 1000.0, Best L1 ratio: 0.1

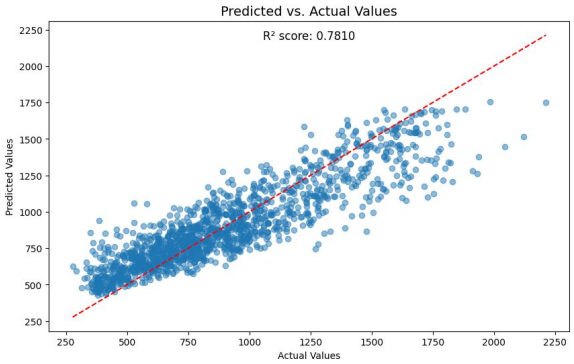
Comparison of Linear Models



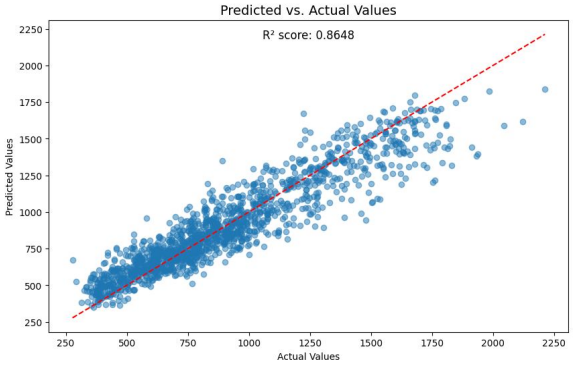
Exploring the Potential Connection - Model Fitting

II - Non-linear Models

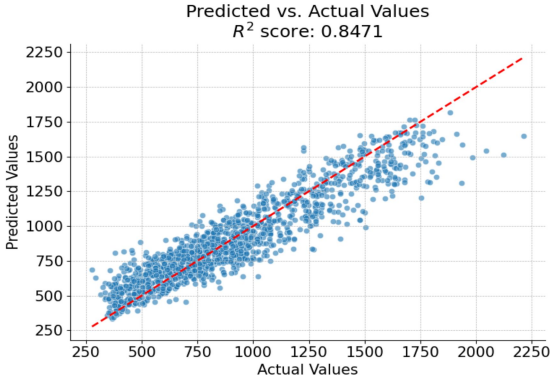
1. Random Forest



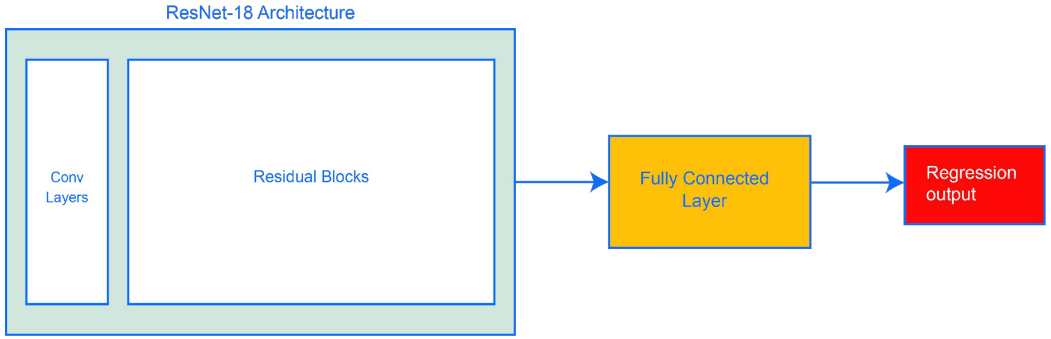
2. XGBoost

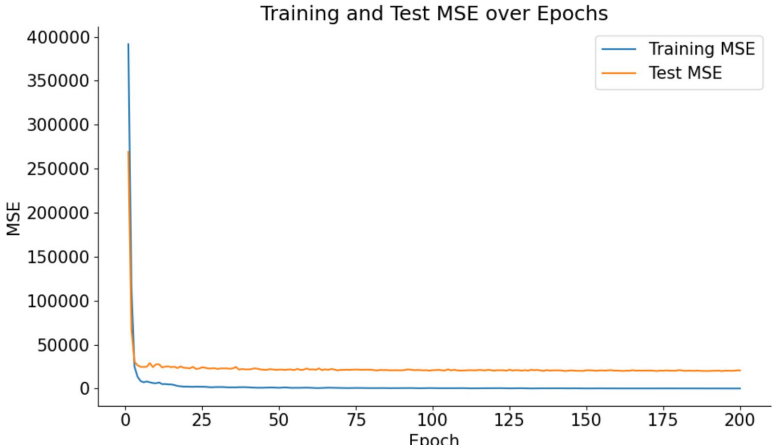


3. ResNet-18



Model architecture and training



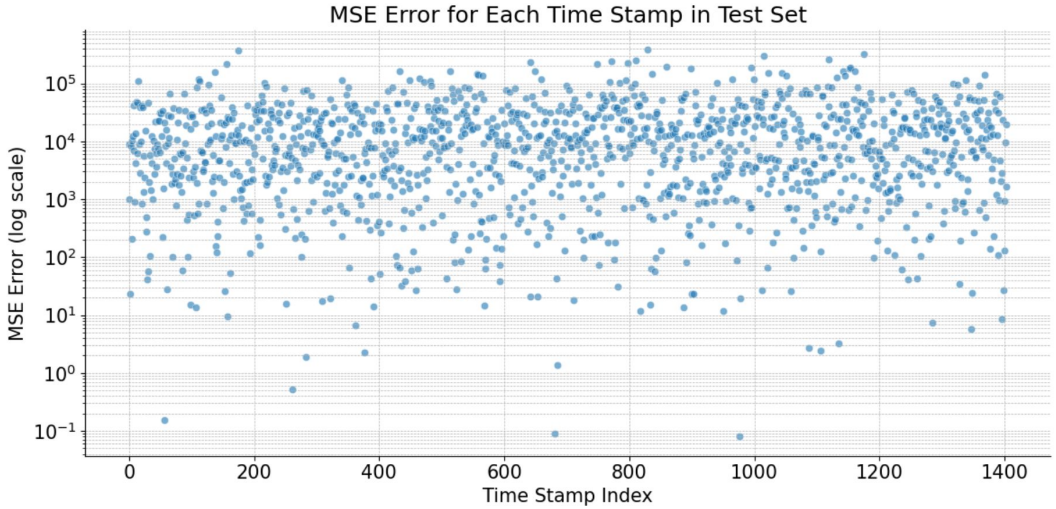


Resnet-18; with fully connected layer added for regression task; Adam optimizer with weight decay; 200 epochs.

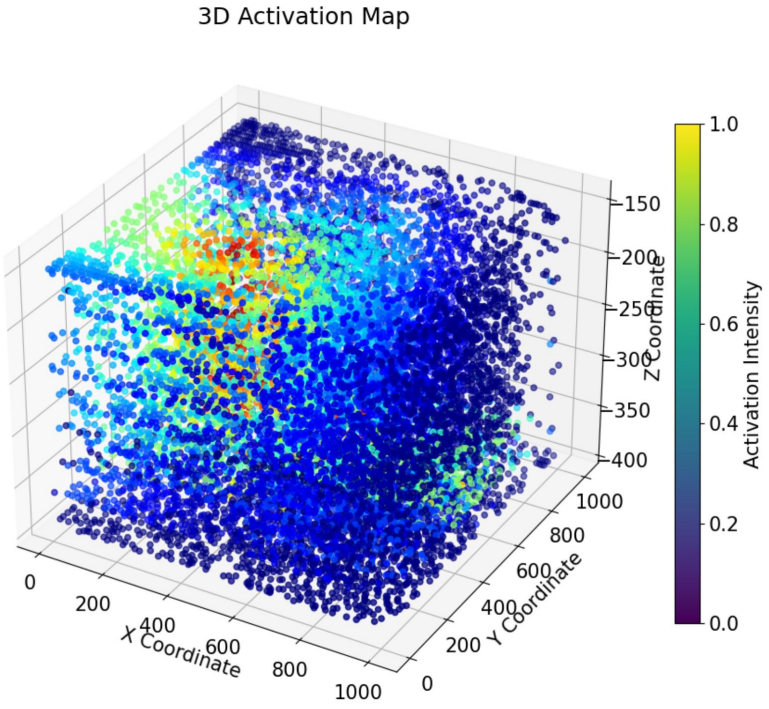
CNN - Result

R2 score: 0.84; MSE error: 20712

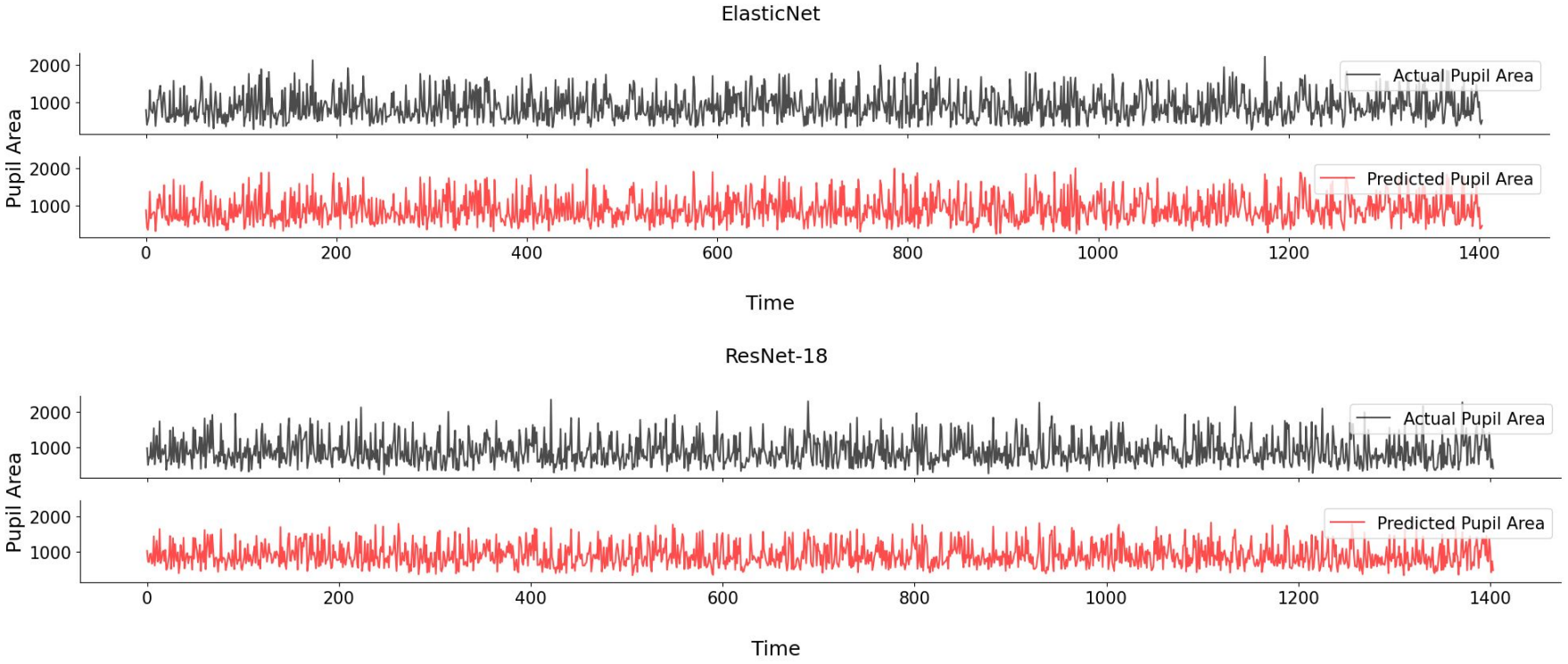
```
Top 100 Errors:
Time Stamp: 829, MSE Error: 388332.84375
Time Stamp: 175, MSE Error: 369265.5625
Time Stamp: 1175, MSE Error: 321395.0
Time Stamp: 1015, MSE Error: 301238.3125
Time Stamp: 1118, MSE Error: 261429.546875
Time Stamp: 810, MSE Error: 253822.734375
Time Stamp: 771, MSE Error: 240873.90625
Time Stamp: 642, MSE Error: 233071.484375
Time Stamp: 797, MSE Error: 229221.203125
Time Stamp: 748, MSE Error: 220510.609375
Time Stamp: 156, MSE Error: 215029.984375
Time Stamp: 859, MSE Error: 192880.734375
Time Stamp: 995, MSE Error: 188778.046875
Time Stamp: 1153, MSE Error: 187416.0625
Time Stamp: 898, MSE Error: 183370.546875
Time Stamp: 1152, MSE Error: 181521.96875
Time Stamp: 1161, MSE Error: 166053.46875
```



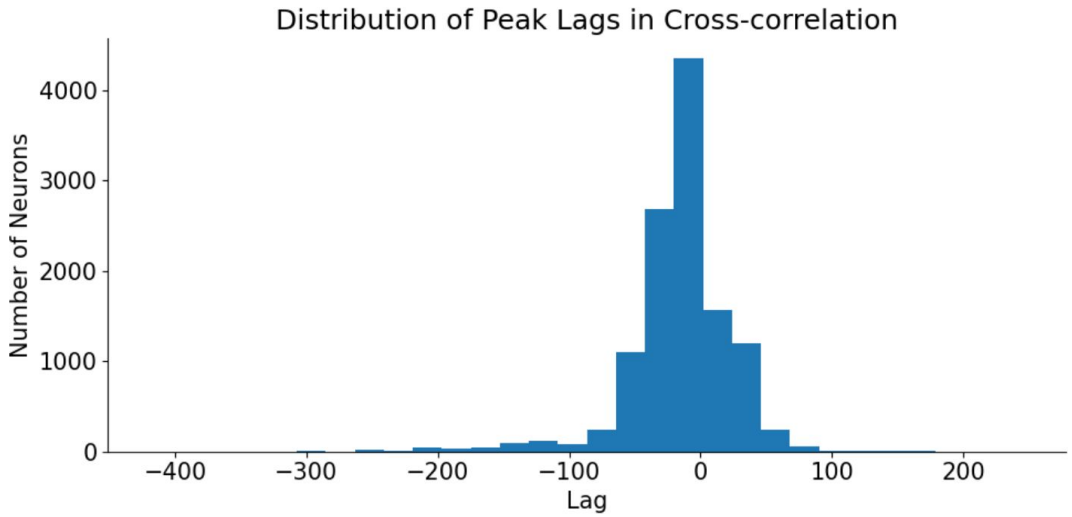
CNN - Visualizing Activation Maps



Decoded pupil area from V1 population



Lag between Neuronal Firing and Pupil Size Change

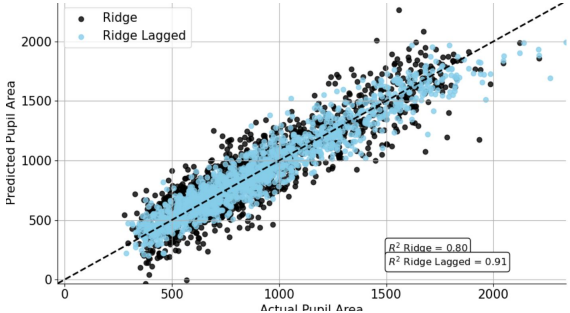


Top 10 Lag Counts:

	Lag	Count
56	-1	1146
55	-2	876
57	0	630
54	-3	327
58	1	247
28	-30	207
27	-31	188
26	-32	172
29	-29	162
53	-4	146

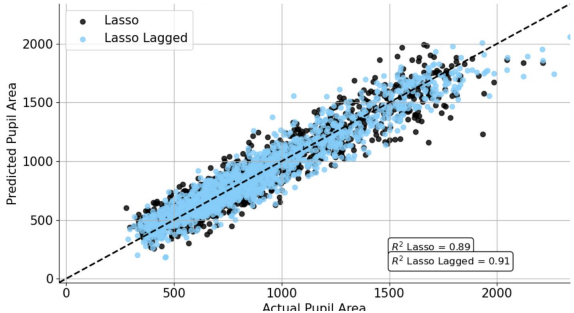
Model fitting on lagged features

Ridge Regression



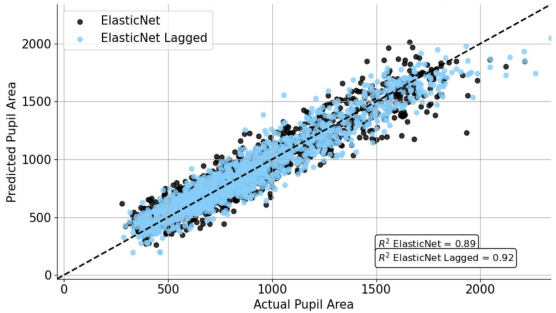

```
R^2 Score: 0.91
Best Alpha: 1000000.0
```

Lasso Regression




```
R^2 Score: 0.91
Best Alpha: 100.0
```

ElasticNet




```
R^2 Score: 0.92
Best Alpha: 1000.0
Best L1 Ratio: 0.1
```

What comes next?

- Explore further the **biological relevance** of the lag between neural firing and pupil area changes

- Exploring non-linear models and deep neural networks with lag to **capture complex relationships**

What comes next?

- Pupil size is affected by states of **arousal**, and understanding pupil size may help in this area (Salkoff et al, 2019)
- V1 has been associated with **skill acquisition** (Zhang, 2023)
- V1 in blind people can be recruited for **tactile inputs** and **language tasks** (Satian, 2005)

References

Sathian, K. (2005), Visual cortical activity during tactile perception in the sighted and the visually deprived. Dev. Psychobiol., 46: 279-286. https://doi.org/10.1002/dev.20056.

Zhang A, Zador AM (2023) Neurons in the primary visual cortex of freely moving rats encode both sensory and non-sensory task variables. PLoS Biol 21(12): e3002384. https://doi.org/10.1371/journal.pbio.3002384.

Salkoff, D.B., Zagha, E., McCarthy, E., & McCormick, D.A. (2019). Movement and Performance Explain Widespread Cortical Activity in a Visual Detection Task. *Cerebral cortex*.

He, K., Zhang, X., Ren, S., & Sun, J. (2015). Deep Residual Learning for Image Recognition. *ArXiv*. /abs/1512.03385