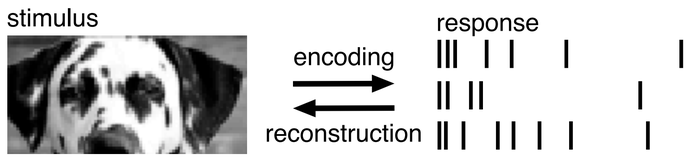
Reconstruction of natural images from responses of primate retinal ganglion cells

Nora Brackbill[1], Nikhil Parthasarathy[1], Orren Karniol-Tambour[1], Colleen Rhoades[1], Nishal Shah[1], Georges Goetz[1], Alexandra Tikidji-Hamburyan[1], Alexander Sher[2], Alan M. Litke[2], and E.J. Chichilnisky[1]

1. Stanford University, 2. University of California, Santa Cruz

Background

Visual signaling by the retina is often probed by studying how retinal ganglion cells (RGCs) encode the visual stimuli. A complementary approach is to reconstruct the stimulus from RGC responses [1-3]. This provides a view of what information RGCs transmit about the visual scene in the domain of the stimulus, rather than neural responses.

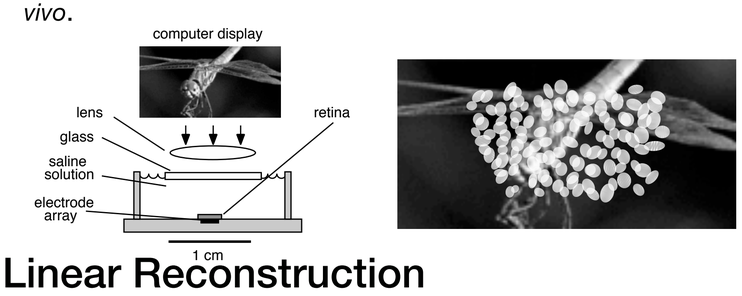


Here, we investigate reconstruction from primate RGCs.

- How do multiple cell types combine to create a representation of the image?
- What is the visual signal sent by an individual RGC in the context of the population?

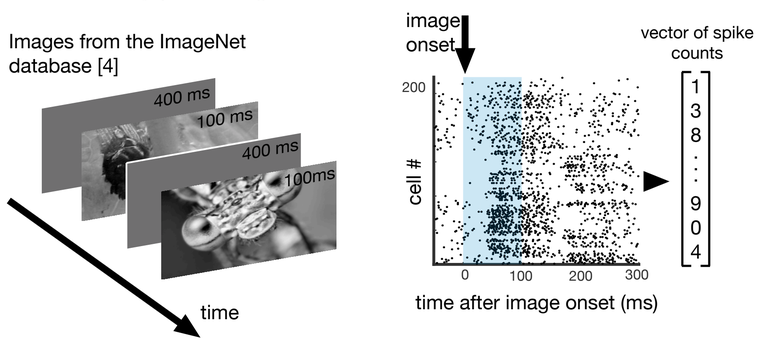
Methods

Populations of retinal ganglion cells were recorded using a large-scale multielectrode array in peripheral macaque retina *ex vivo*.



Linear Reconstruction

Least squares regression was performed to calculate reconstruction filters. Reconstruction performance was calculated by predicting the stimulus on held out data.



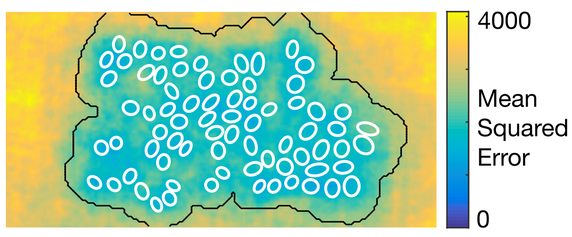
$$\underset{\text{pixels x images}}{\textbf{S}\text{timulus}} = \underset{\text{pixels x cells}}{\textbf{W}\text{eights}} \cdot \underset{\text{cells x images}}{\textbf{R}\text{esponses}}$$

Least Squares Solution $W_{ls} = (R^T R)^{-1} R^T S$

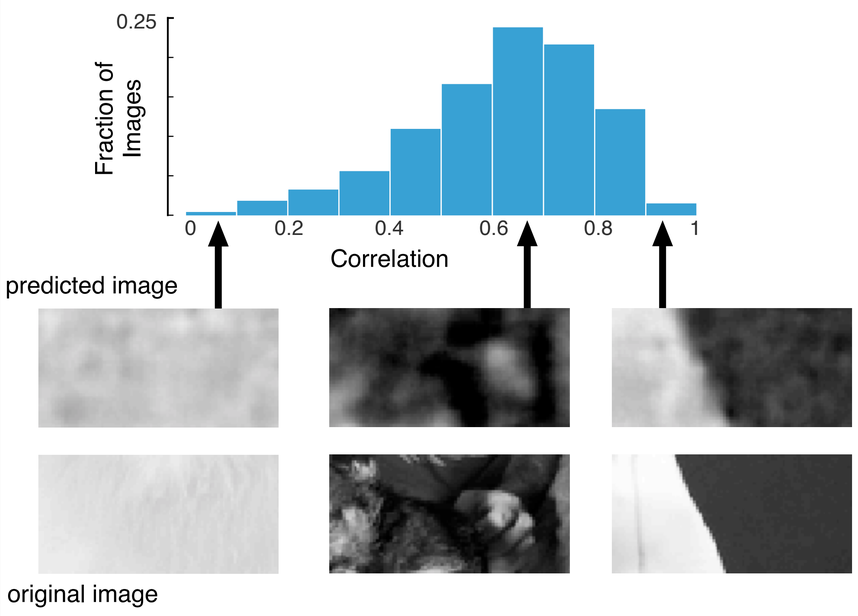
Testing model on held out data $\hat{Y} = W_{ls} R_{\text{held out}}$

Data was collected from three preparations of retina (images, ON parasol cells, OFF parasol cells): (7200, 58, 72), (10000, 93, 74), (17000, 42, 64). Estimates of the model parameters *W* were close to asymptotic in the amount of data.

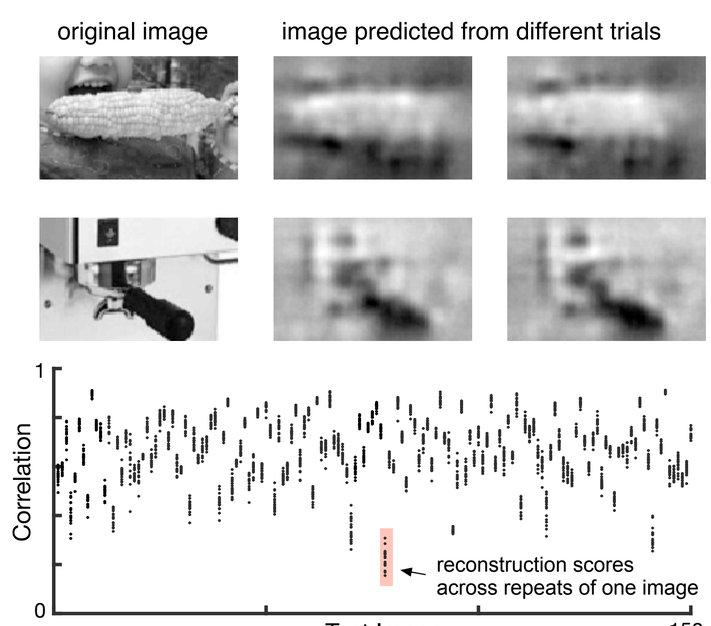
Model performance was measured over region covered by RGCs.



How well can we reconstruct the visual stimulus from RGC responses?



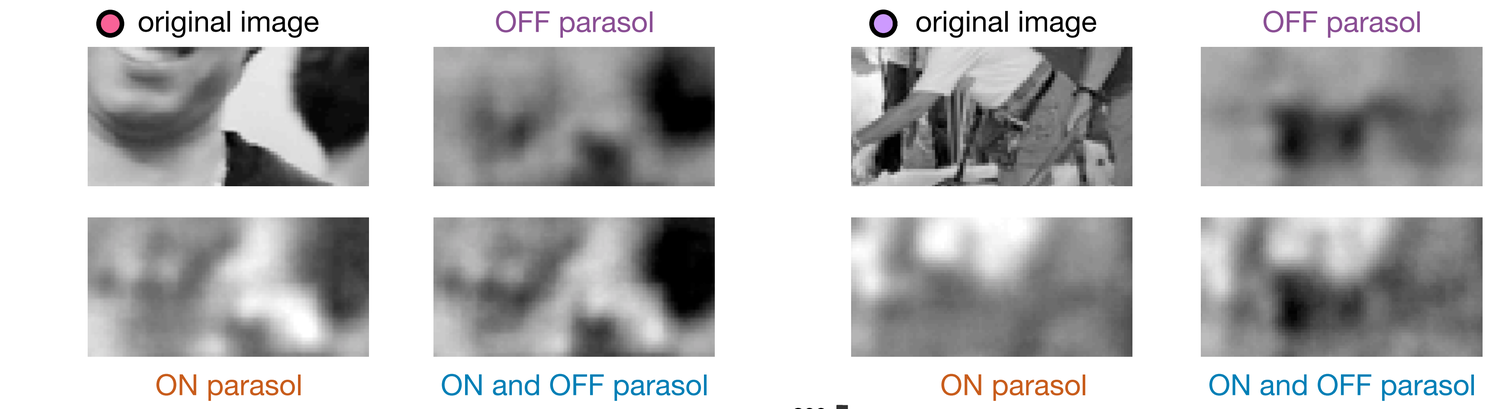
A linear model produces fairly accurate reconstructions, and some types of images are reconstructed better than others.

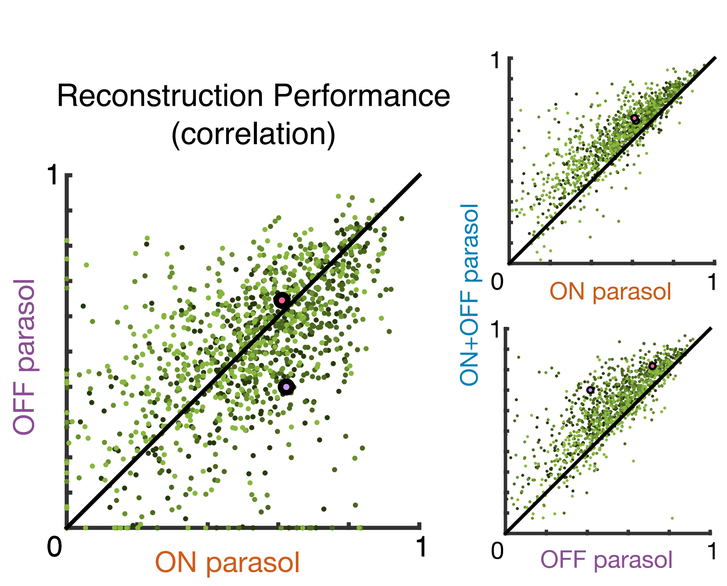


The trial-to-trial variability of the reconstruction is low compared to the variability between images.

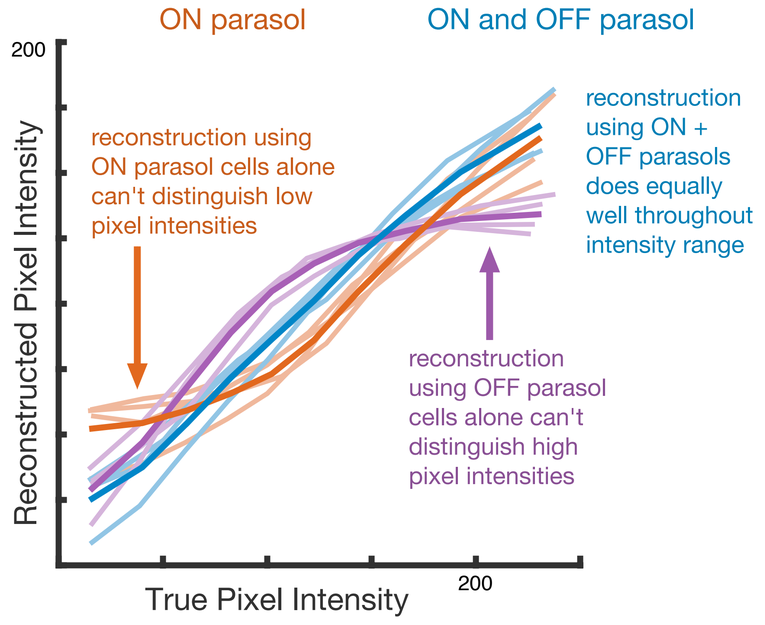
A linear model produces resonable estimates of the visual stimulus from single-trial RGC responses.

How do ON and OFF cell types represent the image?





Reconstruction using either ON or OFF parasols yielded similar performance, and using both was best.

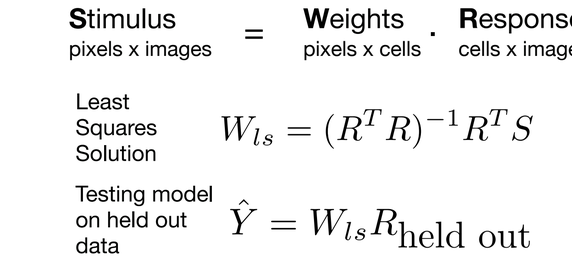


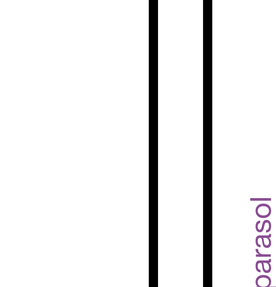
Reconstruction with only ON cells failed to accurately capture dark areas of the image, and vice versa.

ON and OFF populations encode different ranges of contrast, and both are needed to reconstruct the image.

Is the spatial signal independent?

image predicted from shuffled responses



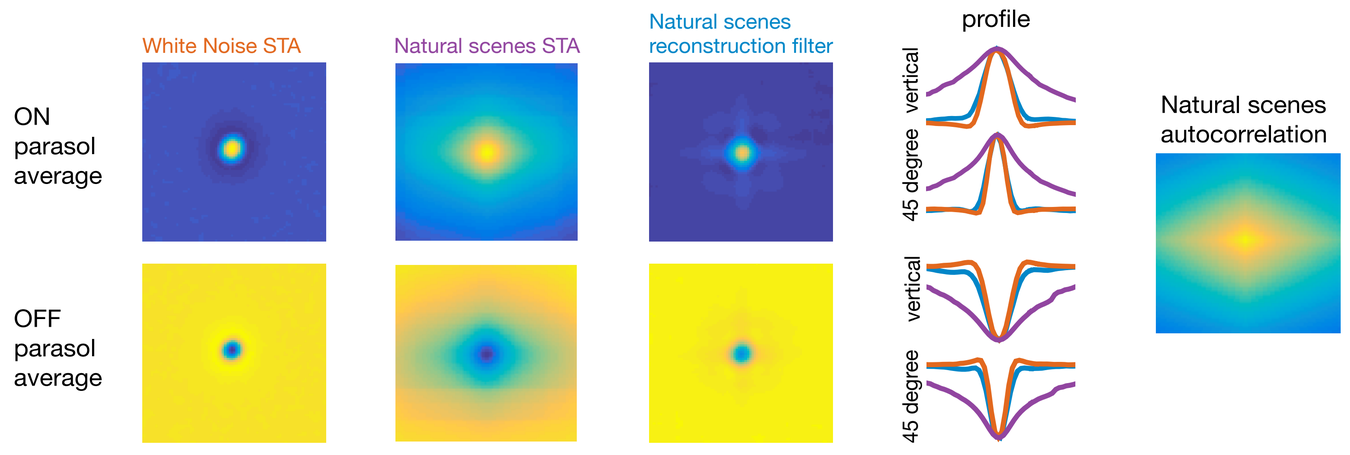


Using cell responses from different trials doesn't affect reconstruction, suggesting that correlated activity is not being used.

The reconstruction filter is mostly unaffected by the inclusion of another cell type.

Shuffling and filter shapes reveal little interaction between RGCs.

What is the spatial message sent by a RGC?



Reconstruction filters resemble white noise STA with hints of natural scenes structure.

References

[1] David K. Warland, Pamela Reinagel, and Markus Meister. Decoding visual information from a population of retinal ganglion cells. Journal of neurophysiology, 78(5):2336-2350, 1997.

[2] Garrett B. Stanley, Fei F. Li, and Yang Dan. Reconstruction of natural scenes from ensemble responses in the lateral geniculate nucleus. Journal of Neuroscience, 19(18):8036-8042, 1999.

[3] Fred Rieke, Davd Warland, Rob de Ruyter van Steveninck, and William Bialek. Spikes: Exploring the Neural Code. MIT Press, Cambridge, MA, USA, 1999.

[4] Jia Deng, Wei Dong, Richard Socher, Li-Jia Li, Kai Li, and Li Fei-Fei. Imagenet: A large-scale hierarchical image database. In Computer Vision and Pattern Recognition, 2009. CVPR 2009. IEEE Conference on, pages 248-255. IEEE, 2009.

[5] Nikhil Parthasarathy, Eleanor Batty, William Falcon, Thomas Rutten, Mohit Rajpal, E. J. Chichilnisky, Liam Paninski. Neural Networks for Efficient Bayesian Decoding of Natural Images from Retinal Neurons. bioarxiv, https://doi.org/10.1101/153759.

Future Work

- building on the linear model [5]
- incorporating more cell types
- further investigation of the visual message and independence
- spatiotemporal reconstructions.

Acknowledgements

This work was supported by NSF GRFP DGE-114747 and NSF IGERT 0801700 (N.B.), NEI F31EY027166 (C.R.), Stanford Neurosciences Institute Interdisciplinary Fellowship (G.G.), Pew Charitable Trusts Fellowship in Biomedical Sciences (A.S.), NIH R01EY017992 and NSF/NIH CRCNS Grant IIS-1430348 (E.J.C.). We thank Jill Desnoyer for technical assistance, and Corinna Darian-Smith and Tirin Moore (Stanford), Jose Carmena and Jack Gallant (UC Berkeley), Jonathan Horton (UCSF), and the UC Davis Primate Center for access to primate retinas.