Dissecting the processing of color vision in the primary visual cortex (V1) at the center-of-gaze

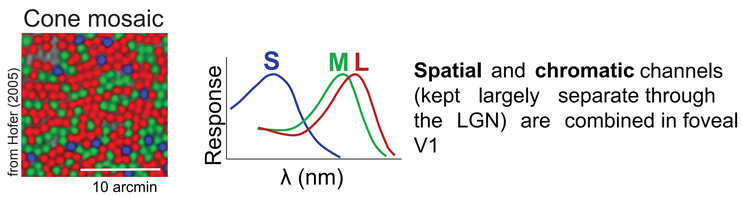
Felix Bartsch[1,2,3], Jacob L. Yates[1,4], Cole Saborio[1], Daniel A. Butts[1,2], Bevil R. Conway[3]

[1]Department of Biology, [2]Program in Neuroscience and Cognitive Science, University of Maryland, College Park, MD, USA
[3]Laboratory of Sensorimotor Research, National Eye Institute, National Institutes of Health, Bethesda, MD, USA
[4]Herbert Wertheim School of Optometry and Vision Science, University of California, Berkeley, CA, USA

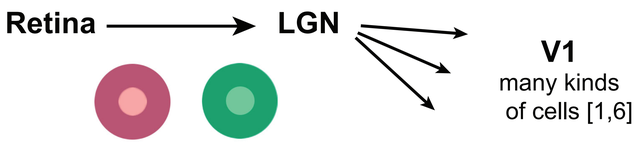
Background

How does the cortex process high-acuity vision?

High-acuity occurs in the **fovea**, within the center 1° of visual angle. Perception is at cone resolution (1 arcmin or 1/60°). Pre-cortical circuitry is at this resolution.

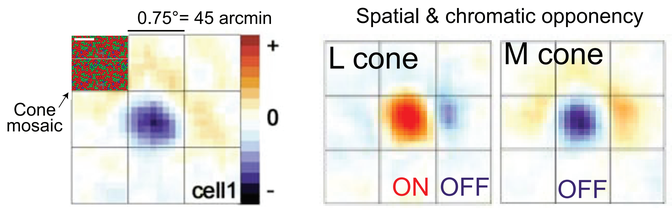


Spatial and **chromatic** channels (kept largely separate through the LGN) are combined in foveal V1



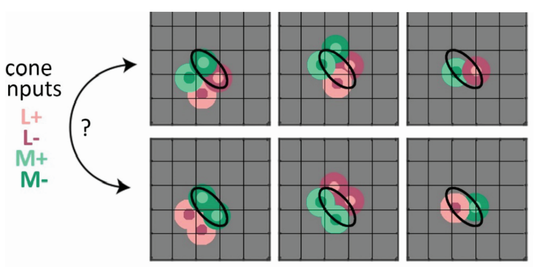
Foveal V1 is all but unstudied

V1 neurons are typically studied in parafovea (>2°) and higher to avoid problems with knowing the true eye position, which must be at ~arcmin resolution for fovea V1.



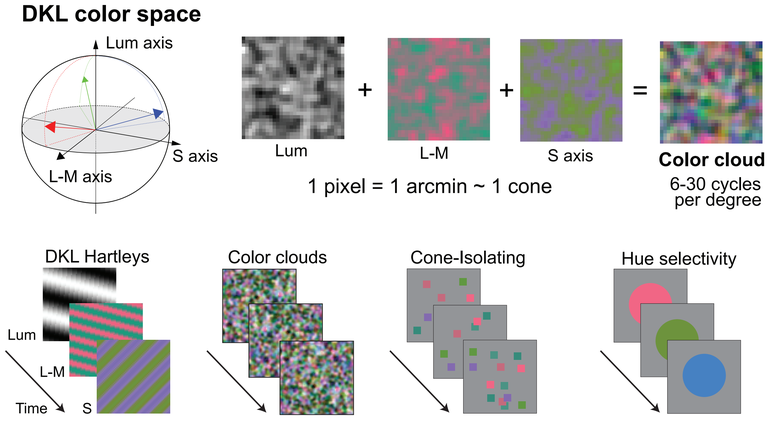
How is spatial and chromatic information combined in foveal V1?

V1 neurons are typically nonlinear, and mixing of spatial and chromatic information will only be clear with nonlinear models.



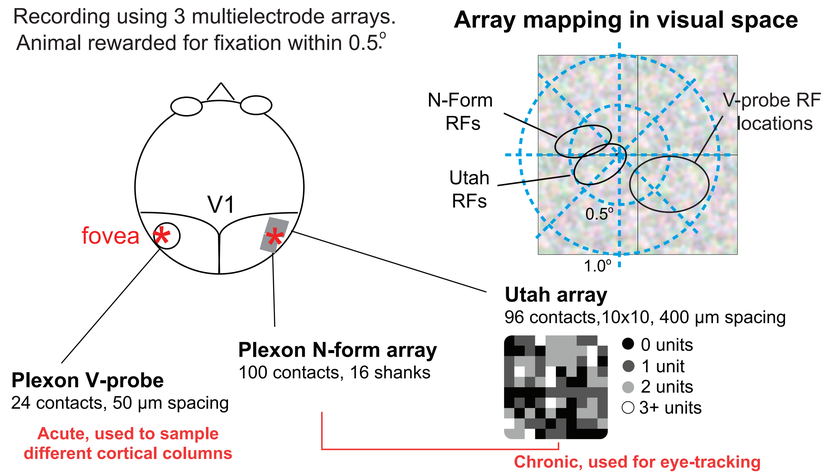
Spatio-chromatic stimuli

DKL color space



Large-scale recordings from foveal V1

Recording using 3 multielectrode arrays.
Animal rewarded for fixation within 0.5°.



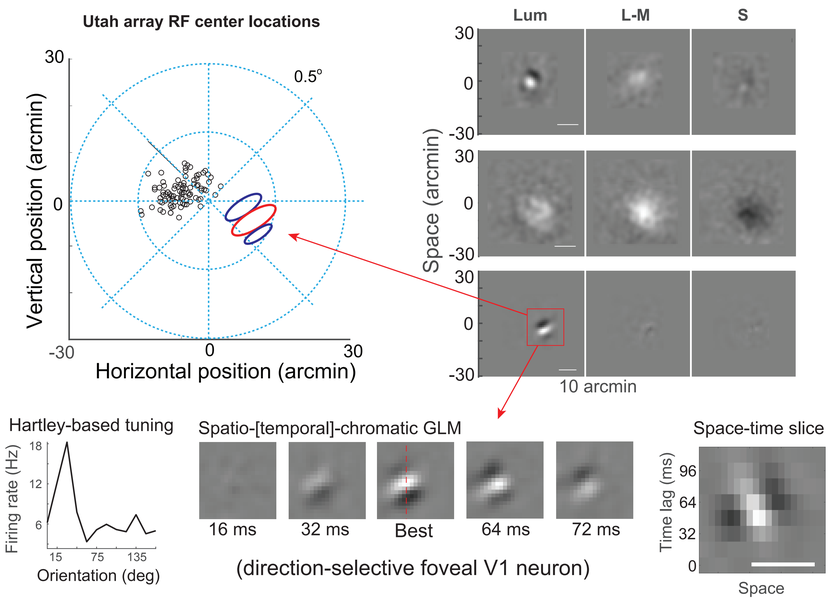
Computation across the cortical column

We sample a different cortical column with the V-probe in each experiment, and can use population models to understand how spatio-chromatic selectivity is constructed across the cortical column.

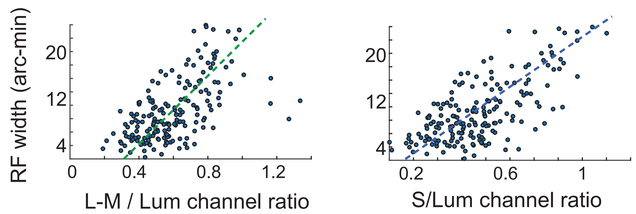
Model-based eye tracking

To infer the eye-position precisely, we use the population activity of foveal V1 neurons [4] combined with deep neural network models of each neuron.

Spatio-chromatic selectivity in foveal V1



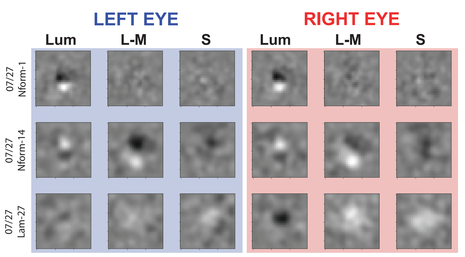
Relationship between color selectivity and RF size in fovea



Other preliminary analyses

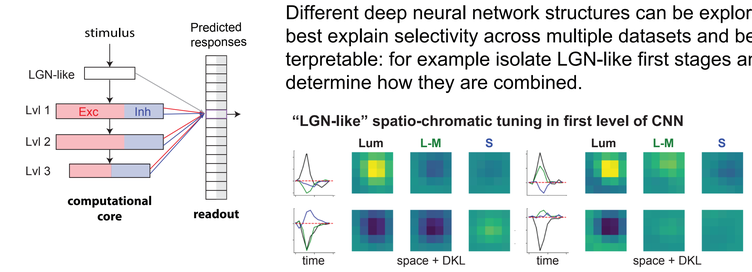
Binocular GLMs can isolate each eye's S-C selectivity

Neurons were recorded during both binocular and monocular (one eye occluded) stimulation. GLMs could isolate the contributions of each eye, and set the stage for simulatneous model-based binocular eye tracking.



Deep neural networks to trace the construction of S-C selectivity across (different) cortical columns

Different deep neural network structures can be explored to best explain selectivity across multiple datasets and be interpretable: for example isolate LGN-like first stages and determine how they are combined.



References

[1] Hubel, D. H., & Wiesel, T. N. (2004). Brain and visual perception: the story of a 25-year collaboration. Oxford Univ Press.
[2] Conway, B. R. (2001). Spatial structure of cone inputs to color cells in alert macaque V-1. J Neurosci, 21(8), 2768-83.
[3] Hofer, H., Carroll, J., Neitz, J., Neitz, M., & Williams, D. R. (2005). Organization of the human trichromatic cone mosaic. J Neurosci, 25(42), 9669-9679.
[4] McFarland JM, Cui Y, Butts DA (2013) Inferring nonlinear neuronal computation based on physiologically plausible inputs. PLoS Comput Biology 9(7), e1003143.
[5] McFarland, J. M., Bondy, A. G., Cumming, B. G., & Butts, D. A. (2014). High-resolution eye tracking using V1 neuron activity. Nat comms, 5(1), 1-12.
[6] Horwitz, G. D. (2020). Signals related to color in the early visual cortex. Annual Review of Vision Science, 6, 287-311.
[7] Lurz K-K, Bashiri M, Willeke K, et al. Generalization in data- driven models of V1. bioRxiv: 10.1101/2020.10.05.326256
[8] Yates JL, Coop S, Wu RJ, Butts DA, Rucci M, Mitchell JF (2021) Beyond fixation: detailed characterization of neural selectivity in free-viewing primates. bioRxiv: 10.1101/2021.11.06.467566.

This work supported by NSF IIS-2113197 (FB, JLY, CS, DAB) and the NIH intramural program (BRC, FB).