**Specific aims**

The retina has to compress the visual world so that it can be sent to the cortex through the optic nerve. This information is separated into multiple pathways, with each pathway processing specific visual information. These pathways do not encode all information in visual scenes, but instead focus on encoding specific patterns of stimuli. While we know what visual information is encoded by these neurons, physiology cannot tell us *why* the receptive fields of neurons are how they are. To understand how the retina processes information, we need quantitative theories that can explain retinal physiology. The efficient coding hypothesis is one of the most successful theories in this vein, which states that the retina should remove redundancies to maximize the amount of information transmitted to the brain through the finite-size optic nerve. This hypothesis has can explain many features of retinal encoding such as center-surround receptive fields and ON-OFF pathways1-5. However, most of these models assume an infinite number of neurons, which makes it difficult for these models to make predictions about how the retina should select what information to send through the finite-size optic nerve. My project will make such predictions by using machine learning to build a more flexible efficient coding model that assumes a limited number of neurons. More specifically, I will provide efficient coding predictions about how the retina should process chromatic inputs (Aim 1), and about how the retina should process motion (Aim 2). By comparing these results with experimental data, we will learn how many properties of retinal receptive fields can be explained by efficient coding principles.

**Aim 1: Expand efficient coding models to encompass chromatic information**

Encoding colors starts at the level of cone photoreceptors in the retina, which come in three types: Long (L), Medium (M), and Short (S), roughly encoding red, green and blue stimuli, respectively6. Most retinal ganglion cells (RGCs) in the fovea are color-opponent, meaning they are excited by one color and inhibited by another. While color-opponency can be explained by efficient coding principles7, 8, these models fail to explain red-green opponency in midget cells, which represent 80% of RGCs in the fovea. These models instead predict that most RGCs in the fovea should add L and M cones. This phenomenon only occurs in parasol cells, which represent about 10% of RGCs. The remaining 10% of RGCs are bistratified cells, which integrate ON inputs from S cones and OFF inputs from L and M cones. Bistratified cells are unique in that they asymmetric, and are the only major cell type to have an ON but not an OFF pathway. My model will try to explain two major findings: 1) Why this asymmetry in bistratified cells occurs, and 2) why midget cells represent most neurons in the fovea despite encoding events that rarely occur in natural images. Completion of this aim will inform us whether efficient coding can successfully explain how the retina processes color in different pathways.

**Aim 2: Expand efficient coding models to explain motion-selectivity in RGCs**

Visual scenes typically involve movement,, either because of objects moving or optic flow from our own movements. The encoding of visual motion starts as early as the retina, with several subtypes of retinal ganglion cells (RGCs) having stronger responses to one direction of motion than to its opposite9, 10. The major type of motion-encoding RGCs are ON-OFF direction-selective ganglion cells (DSGC)11, which are divided into four subtypes that respond preferentially to each of the four cardinal directions10. I hypothesize that these populations emerge naturally from efficient coding principles. Where previous models assumed independent spatial and temporal receptive fields that are incapable of capturing motion responsiveness, I will build an efficient coding model that allows for fully general spatiotemporal receptive fields. I will then test whether this model, trained to efficiently encode natural movies, successfully replicates ON-OFF DSGCs that only encode the four cardinal directions10. To further validate the model, we will also test novel predictions against experimental data from the Field Lab at UCLA. Completion of this aim will enlighten us as to whether efficient coding can explain the receptive field properties of direction-selective ganglion cells.

**References**

1. Atick, J.J. and A.N. Redlich, *Towards a theory of early visual processing.* Neural computation, 1990. **2**(3): p. 308-320.

2. Atick, J.J. and A.N. Redlich, *What does the retina know about natural scenes?* Neural computation, 1992. **4**(2): p. 196-210.

3. Karklin, Y. and E. Simoncelli, *Efficient coding of natural images with a population of noisy linear-nonlinear neurons.* Advances in neural information processing systems, 2011. **24**.

4. Balasubramanian, V. and M.J. Berry II, *A test of metabolically efficient coding in the retina.* Network: Computation in Neural Systems, 2002. **13**(4): p. 531.

5. Doi, E., et al., *Efficient coding of spatial information in the primate retina.* Journal of Neuroscience, 2012. **32**(46): p. 16256-16264.

6. Crook, J.D., et al., *Horizontal cell feedback without cone type-selective inhibition mediates “red–green” color opponency in midget ganglion cells of the primate retina.* Journal of Neuroscience, 2011. **31**(5): p. 1762-1772.

7. Atick, J.J., Z. Li, and A.N. Redlich, *Understanding retinal color coding from first principles.* Neural computation, 1992. **4**(4): p. 559-572.

8. Lee, T.-W., T. Wachtler, and T.J. Sejnowski, *Color opponency is an efficient representation of spectral properties in natural scenes.* Vision Research, 2002. **42**(17): p. 2095-2103.

9. Rasmussen, R. and K. Yonehara, *Contributions of retinal direction selectivity to central visual processing.* Current Biology, 2020. **30**(15): p. R897-R903.

10. Vaney, D.I., B. Sivyer, and W.R. Taylor, *Direction selectivity in the retina: symmetry and asymmetry in structure and function.* Nature Reviews Neuroscience, 2012. **13**(3): p. 194-208.

11. Wei, W., et al., *Development of asymmetric inhibition underlying direction selectivity in the retina.* Nature, 2011. **469**(7330): p. 402-406.