Specific aims

One of the primary goals in neuroscience is to figure out simple principles that explain how nervous systems are organized. One of the most successful theories in this vein states that sensory systems should remove redundancies in their inputs to optimize the information they process[5]. This *efficient coding hypothesis* provides us with a mathematical framework to understand how neurons *should* encode information, which can then be experimentally tested against how neurons *actually* do so. Over the past 60 years, efficient coding has successfully explained many experimental findings in different sensory modalities such as vision[4, 10, 15, 24, 25, 28], audition[20] and touch[23]. This hypothesis has been especially successful in the retina, where it can explain many features of retinal encoding such as center-surround receptive fields and ON-OFF pathways[2-4, 10, 15]. However, we still lack efficient coding predictions for how the retina processes many complex features of the visual world such as color and motion. My work will tackle this problem by providing a theoretical account of how the retina integrates redundant inputs across different color channels (Aim 1) and across time (Aim 2). These results extend our understanding of how retinal physiology can be explained by efficient coding principles.

Aim 1: Expand efficient coding models to encompass chromatic information

Color is a crucial aspect of how we perceive the visual world. Encoding colors starts at the level of cone photoreceptors in the fovea of the retina, which come in three types –Long (L), Medium (M), and Short (S), roughly encoding red, green and blue stimuli, respectively[8]. This color information is ultimately encoded by RGCs, with different types integrating cone inputs differently. Most RGCs (~90% in the fovea and ~45% in the periphery) are midget cells[9], which, in the fovea, are 'red-green opponent' and encode a contrast between L and M inputs[7-9]. In the periphery, these midget cells are not red-green opponent but instead sum L and M cone inputs[7, 9, 22]. Why midget cells use different coding strategies for the fovea and for the periphery is still unclear. We hypothesize those different strategies have to do with the ratio between RGCs and cones in the fovea versus the periphery. While the periphery has more cones than RGCs, the opposite is true for the primate fovea, with approximately 3 RGCs for every cone[30]. Here we will test that hypothesis by building an efficient coding model for chromatic natural images. We will try to replicate the differences in receptive fields between the fovea and the periphery by building efficient coding models with different RGC-cone ratios. We will also test whether we can replicate receptive fields of RGC types other than midget cells, such as parasol and bistratified cells. Completion of this aim will grant us a theoretical understanding of how the retina processes chromatic information.

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

Visual scenes are typically in motion, 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 opposite[26, 29]. The major type of motion encoding RGCs are ON-OFF direction-selective ganglion cells[31], which are divided into four subtypes that respond preferentially to each of the four cardinal directions[29]. Yet it is still not known whether or how efficient coding principles can explain this finding. My lab previously studied efficient coding in spatiotemporal receptive fields[12], but this study made strong assumptions (independently processed spatial and temporal information) that preclude encoding visual motion. To test whether we can explain motion-selectivity in RGCs from efficient coding principles, I will build an efficient coding model that estimates receptive fields in which space and time are processed together. I predict the efficient coding model will be able to replicate direction selectivity in RGCs, and that we will find four subtypes that encode motion in the four cardinal directions[29]. Completion of this aim will result in testable predictions for efficient coding of motion in natural images, which we will be able to compare to experimental data from the Field Lab at UCLA.