David St-Amand

**Specific Aims**

One of the primary goals in neuroscience is to figure out simple principles that explain how systems are organized. Barlow (1961) proposed one of the most successful theories in neuroscience, which states that sensory neurons should be efficient – they should optimize the amount of information they process, while also keeping their firing rates to a minimum. This *efficient coding hypothesis* provides us with a mathematical framework to understand how neurons should encode information, which can then be verified experimentally. Efficient coding has been successful at explaining how neuronal information is processed in multiple brain regions including the retina, the primary auditory cortex and the primary motor cortex. To reduce the overall number of spikes, this hypothesis states that sensory information must encode unexpected events – that is, discrepancies between inputs that are redundant. This strategy becomes less and less efficient as the redundancies between inputs increase, since the redundancies represent a larger fraction of the total information. When the redundancies are too high, efficient coding predicts that neurons should stop encoding discrepancies and instead sum redundant inputs. However, this is not how sensory neurons integrate redundant information; they encode discrepancies between their inputs instead of the sum, despite the huge loss of information. My project will reconcile predictions from efficient coding with empirical findings; *My central hypothesis is that encoding discrepancies between inputs that are highly correlated is efficient.*

The efficient coding hypothesis has been especially successful at predicting experimental findings in the retina, which makes this system perfect for studying how neurons should efficiently integrate redundant inputs. Efficient coding successfully explains why retinal ganglion cells (RGCs) have center-surround receptive fields, and why RGCs are organized into different functional types, with each type having neurons tiling the entire retina to form a ‘mosaic’. Recently, my lab used efficient coding to explain whether different mosaics should be spatially aligned or anti-aligned, which depends on whether the internal noise levels of RGCs is low or high (Jun, Field & Pearson, 2021). I will use similar models to study the optimal strategy to integrate redundant inputs in the retina, both across different channels (aim 1) and across time (aim 2).

**Aim 1:** Determine how RGCs should efficiently integrate redundant input channels

Hypothesis: The efficient strategy is to encode discrepancies between redundant channels

Retinal ganglion cells integrate inputs from cone photoreceptors, which are split into three different channels: Long (L), Medium (M) and Short (S) cones. The information in these three channels is mostly redundant, with most (~95%) of the information in natural images being achromatic. However, how the retina works seems to contradict that principle: Most RGCs’ responses are tuned to colors, with each neuron type processing a specific color channel. My project will reconcile these two principles and explain why encoding chromatic information is the optimal efficient coding strategy for natural images. To do so, I will build and train an efficient coding model on chromatic natural images and draw parallels from the model neurons to retinal experimental data. Completion of this aim will allow us to understand why it is efficient for neurons to encode discrepancies between redundant input channels.

**Aim 2:** Determine how the retina should encode spatiotemporal correlations across inputs

Hypothesis: We can replicate how the retina encodes motion from efficient coding principles

Neuronal activity is not only correlated in both space and time, but spatial and temporal correlations also interact with each other. The most prominent example of this phenomenon is motion, where we can predict the future location of a moving object based on its current location and velocity. While it is clear that the efficient coding strategy for RGCs should include encoding motion, what exactly this strategy is – how many neurons should process motion and what should their spatiotemporal receptive fields be– is still unclear*. My working hypothesis is that the efficient coding strategy for encoding motion in natural images will replicate experimental findings about motion encoding in RGCs.* To answer this question, I will extend the previous spatiotemporal efficient coding model from my lab to be spatiotemporally inseparable; that is, the model will be able to learn a receptive field that changes across time, a crucial property to encode motion. Completion of this aim will enlighten us as to whether how the retina encodes motion can be fully explained by the efficient coding hypothesis.