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 states that sensory information must be compressed to reduce the overall number of spikes. This compression occurs by encoding unexpected events, or discrepancies between inputs that are correlated. Information is lost during compression, which means the brain must compromise between encoding as much information as possible and saving energy. This information cost increases as a function of input correlations, which also influences the optimal efficient coding strategy. While a lot of work has been done to understand how sensory neurons should encode inputs that are moderately correlated, how a population of sensory neurons should efficiently encode different inputs that are strongly correlated is still unclear.

To better understand how the efficient coding hypothesis handles correlated inputs, I will train efficient coding models on natural images and compare the optimal coding strategies to what neurons in the early visual system process. The efficient coding hypothesis has been especially successful at predicting experimental findings in the retina, where it explains why retinal ganglion cells (RGCs) have center-surround receptive fields and why these neurons encode color-opponency. Efficient coding also explains why RGCs are organized into different functional types, with each type tiling the entire retina to form a mosaic. My lab recently found that whether different mosaics should be aligned or anti-aligned depends on whether the internal noise levels of RGCs is low or high (Jun, Field & Pearson, 2021). *My central hypothesis is that how RGCs integrate information follows an optimal efficient coding strategy, even with strong input correlations across different color channels or across time.*

**Aim 1:** Determine the optimal efficient coding strategy across correlated color channels

Hypothesis: Retinal Ganglion Cells process color information efficiently

Information in natural images is mostly achromatic, and differences between shades of red and green represent very little of the information. 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 RGCs integrate chromatic information the way they do.

**Aim 2:** Determine the role of motion in optimally encoding natural movies

Hypothesis: The efficient coding strategies for encoding natural movies involves encoding motion.

My lab previously developed a spatiotemporal efficient coding model, where we optimize the receptive fields of neurons in both space and time. We found that as we increase the number of neurons, new cell types with higher temporal and lower spatial frequencies emerge – a finding analogous to retinal parasol cells. However, this model assumed that receptive fields are spatiotemporally separable; that is, the spatial structure of a receptive field does not change across time. Motion is an important feature of natural movies, and such an assumption prevents model neurons from learning the direction of motion. *My working hypothesis is that efficiently encoding natural movies requires encoding motion.* To test this hypothesis, I will build and train an efficient coding model that can learn how receptive fields change across time. Completion of this aim will help us understand why direction selectivity exists as early as the retina in the visual system.

Successful completion of both aims will provide a mathematical understanding how sensory systems should efficiently encode correlated inputs. The immediate impact of this work is an explanation as to why retinal ganglion cells have specific receptive fields. The long-term impact of this work is getting us one step closer to understanding general principles about how sensory systems work.