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 correlated. This strategy becomes less and less efficient as the correlations between inputs increase, since the discrepancies represent a smaller fraction of the total information. When the correlations are too high, efficient coding predicts that neurons should stop encoding discrepancies and instead sum the inputs of the correlated neurons. However, this is not what sensory neurons do; instead, they still encode discrepancies of inputs with very strong correlations, 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: Retinal Ganglion Cells process color information efficiently

Retinal ganglion cells integrate inputs from cone photoreceptors, which are split into three different channels different correlated channels, where each channel represents a different 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.

John’s note September 14th:

Correlations increase redundancies, need extra processing to process redundancies

Don’t use discrepancies, differences, etc.

Ask Liz for her NSF

Same for Kevin