**Understanding binocular visual development as an optimization of innate learning strategies for stereoscopic vision**

Research Proposal for Neil Rao, BS in Biology

## Objective

Develop a set of metrics for scoring derived binocular receptive fields, then use these metrics to search the parameter space of the physiological spontaneous neural activity model. In this way, it will be possible to learn about the expected structure and function of spontaneous activity in the developing visual system.

## Introduction

Highly organized patterns of spontaneous activity have been demonstrated in the developing visual systems of a wide variety of species, including ferrets, mice, monkeys, birds, and turtles. These highly conserved neural activity patterns are bounded, amorphous patterns that form spontaneously, move over time, and dissipate on the order of seconds. The basic question that comes to mind when one see this patterns is “why?” – of all patterns, why these?

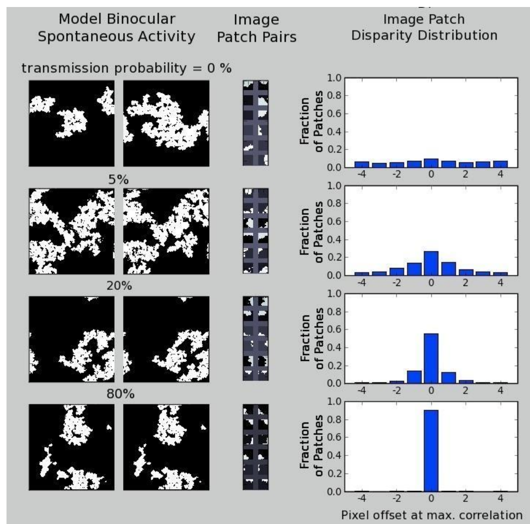


Fig. 1. **One current method of evaluating the binocular model.** Versions of the generated binocular activity patterns (left) with corresponding image patches (middle) and the average point of overlap between patches (right). Although it is understood in visual neuroscience that a “disparity distribution” similar to the middle two patterns is maximally conducive to training a binocular visual system, it is important to find additional metric to properly score these binocular activity patterns. (figure courtesy of Dr. Albert).

Although these patterns do not resemble our natural visual world in appearance, they do contain the same low-level statistical structure as natural scenes. Because of this, these patterns would allow a visual system to adapt in the same way before eye opening to after eye opening.

One of the critical goals of a developing visual system is to process visual information in a behaviorally relevant way as early in development as needed. Binocular vision is necessary for the perception of depth, which can have dramatic consequences for an animal’s survival if not developed in time. Currently published “innate learning” models demonstrate how monocular systems can be developed (Albert et al 2008). The expected patterns from this strategy can be more easily validated, as patterns like retinal waves allow us to visually observe these spontaneous neural patterns using calcium-sensitive dyes. Binocular patterns of spontaneous activity are much more difficult to measure, as they occur in areas like the Lateral Geniculate Nucleus (LGN) which cannot readily be imaged. However, it may be possible to provide deep insights into these binocular patterns by assuming that an approach to development conserved across many species would efficiently prepare the animal for binocular perception.

## Aims and Approach

The ultimate goal of my efforts will be to determine, based on efficient visual coding arguments, the patterns of spontaneous neural activity prior to eye opening which best promote binocular vision after eye opening. To achieve this in a structured approach, I will pursue these efforts through the following four aims, which are ordered more based on dependency.

> **Aim 1:** Implement an efficient version of the current spontaneous activity simulator and efficient coding system.
> **Aim 2:** Find metrics for scoring the developed binocular receptive fields based on receptive field characteristics in physiology
> **Aim 3:** Explore the space of patterns by optimizing the metrics in aim 2.
> **Aim 4:** Use the ability of the filters to produce depth percepts to relate the spontaneous patterns to behaviorally-relevant qualities like depth perception

First, I will implement an efficient method of simulating the spontaneous activity patterns as suggested in an early binocular modeling approach of the Theoretical Neuroscience lab at Loyola. Although the current model produces relevant patterns, this model and the efficient coding algorithm applied to it will need to be made more efficient. Later stages of this project, in particular the optimization aim, will require extremely fast pattern generation and receptive field learning due to the fact that tens of thousands of simulation runs will be required.

Second, I will find direct ways of scoring the binocular receptive fields derived from an efficient coding of these spontaneous patterns. What makes a good binocular receptive field? I will assemble metrics based on known developmental physiology of receptive fields in primary visual cortex, such as spatial frequency tuning, receptive field disparity distribution, etc. A suitable training pattern in this case would be one that develops cells much like those found in developing binocular animals – particularly precocious visual animals that must act on their environment quickly.

> **Steps in optimizing binocular receptive fields**
>
> Pick a set of parameters for pattern generation
> Run the binocular spontaneous neural pattern generator
> Repeat step 2 hundreds of times for enough patterns to derive a set of receptive fields
> Repeat step 3 tens of times to collect enough receptive fields for statistical analysis
> Repeat steps 1-4 hundreds to thousands of times to explore the space of parameters necessary for optimal binocular filters

Third, I will construct an optimization routine that will “close the loop” between the parameters for the pattern generation and the evaluation of the developed binocular receptive fields – exploring the space of neural activity parameters by optimizing the characteristics of the developed receptive fields. This will be challenging for multiple reasons (e.g. one reason for the many simulations necessary to produce adequate numbers of receptive fields is to account for expected high variability).

And finally, I am working with Gordon Kratz, an undergraduate in computer science, who is developing a system that can use binocular receptive fields for depth perception. Although his technique may not be entirely physiologically plausible, it can be used as a way of scoring the efficacy of a set of binocular receptive fields for depth perception. With this, I will demonstrate that it is possible to predict the type of spontaneous neural activity in the developing visual system by optimizing not only indirectly through receptive field properties but also directly by the system's ability to promote depth perception.

**Conclusion**

This work is a demonstration that it is possible to predict properties of spontaneous neural activity by applying high-level principles like efficient coding and innate learning. By assuming that the visual system adapts to endogenously-generated patterns in a similar way to early visual experience, we can estimate the kinds of patterns that should be seen in the developing visual system. This has been demonstrated for monocular spontaneous activity, as it is accessible in the retina and readily imaged using calcium dyes. From this work, we will be able to predict the nature of experimentally measured spontaneous activity in the later, binocular stages of visual development.

**Deliverables/Timeline**

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| June 1st, 2014 | Complete implementing efficient version of activity simulator |
| Sept. 1st, 2014 | Find metrics for binocular receptive fields |
| Jan. 1st, 2015 | Explore space patterns by optimizing algorithm |
| April 15th, 2015 | Produce depth percepts |

**Additional roles and responsibilities**

- Gordon Kratz, undergrad in Computer Science, will be implementing the depth perception algorithm using binocular receptive field models, for directly scoring the efficacy of derived receptive fields for depth perception.

- Dr. Mark V. Albert, professor of Computer Science, heads the Theoretical Neuroscience lab. He will provide guidance on integrating this project with the lab's current work in visual development.