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FUNCTION OF NEURONAL CIRCUITS

We try to understand how large circuits of nerve cells work. In particular we study the visual system, and much of the research has been centered on the very first visual circuit: the retina.

The main challenge for our visual system is to absorb the massive onslaught of raw data from images on the retina and extract from that the few morsels that are needed to guide moment-to-moment behavior. To be concrete: The human eye receives about 1 billion bits per second of raw visual information; of this the owner of that eye uses at most 20 bits per second in deciding what to do. Of course those precious 20 bits are deeply hidden in the raw images, in ways that depend entirely on the task at hand, say playing a piano sonata, or steering a car through traffic. So the biggest mystery of vision is how our neural circuits can boil the billion bits at the input down to 20 bits at the output, and do this in real time, with less than 0.1 second delay. Solving this problem will not only provide a deep answer to how we see, but also allow us to build machine vision systems with such powerful capabilities.

For a long time, the retina of the eye was thought to be a simple camera that encodes the image essentially in raw form and transmits that to the brain. It now emerges that the retina is considerably smarter. It already begins the process of selective filtering, and discards all but a few percent of the raw information it receives. The rest is sent to the brain along ~20 parallel pathways, each of which extracts a different visual feature at each point in the scene. We want to understand:
1) **What** information is encoded by each of these parallel channels? This involves recording the electrical signals from many of the retina's output neurons while stimulating the input receptors with visual patterns (e.g. Zhang 2012, Leonardo 2013). Interpreting the relationship between sensory input and neural output often requires judicious use of mathematical modeling.

2) **How** are these computations performed? For this we gain access to the innards of the retina to track the signals through the various interneurons and synapses (e.g. Asari 2012, 2014). The ultimate goal here is to summarize retinal function with a neural circuit diagram that efficiently simulates the function of the real retina.

3) **Why** the retina is built this way? Much of retinal structure and function is conserved across mammals from mouse to man and probably serves a common purpose. What might this be? Perhaps to pack information efficiently into the optic nerve (e.g. Pitkow 2012, Gjorgjieva 2014); or to facilitate downstream computations of complex visual features (e.g. Güttig 2013); or perhaps to directly extract some signals that are essential for survival (e.g. Yilmaz 2013).

In my new Caltech lab, we start from this core research to explore several new directions. One is a more principled study of visual behavior in the mouse (e.g. Yilmaz 2013). Rather little is known about what these animals do with their eyes, and this needs to change if we want to forge a clear connection between the neural circuits of the visual system and the behaviors they implement. Another direction leads us further into the visual system by simply following the retinal output fibers. Most of them connect to the superior colliculus, a brain area that already integrates vision with other senses and is also intimately involved in the control of action. We are beginning to record neural signals from large circuits in this structure to understand the second stage of visual computations. Finally we are curious to see how animals use all these brain circuits under natural conditions, outside the constraints of the laboratory. For this we have developed a radio-telemetry system that can wirelessly record 64 neural signals in parallel from rodents moving freely in the wild.

**PUBLICATIONS**

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