“Deciphering a Neural Code for Vision”
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Web of Neuroethology

Introduction
Overview

- Decoding the information that eyes transmit to the brain
- Neural images formed by the ensemble of neural network in patterns of coherent activity

Strategy:
1. Videotape the lateral eye’s view of the Limulus’ underwater world
2. Record simultaneously from the optic nerve fiber of an ommatidium viewing the central region of the videotaped scene
3. Compute the ensemble of optic nerve activities in response to the video by using a model of the eye
4. Examine the array of computed responses for putative coding of behaviorally relevant objects

Limulus polyphemus as a model system

- Large neural network
- Large compound eyes
- The optic nerve is up to four inches long, lies just below the carapace
- Integrative mechanisms shared by higher animals
- Its behavior has been well-studied

Passaglia et al., 1998

Visual Cue in Locating Mates

Barlow and Powers (2003):
“The great attraction of the males to the cement castings proved that chemical cues were not involved”

Materials and Methods

- Goal: to understand how the eye encodes visual information in the natural habitat
- Underwater video recording
- Optic nerve recording
- Computing the optic nerve responses - The Cell-Based Model
- Measuring transfer functions
Underwater Video Recording

Passaglia et al., 1997

Optic Nerve Recording

Passaglia et al., 1997

Computing Optic Nerve Responses - The Cell-Based Model

- Incident light intensity
- Integration with lateral and self-inhibitory potentials
- Generator potential
- Voltage fluctuations (quantum bumps)
- Receptor potential
- Train of nerve impulses

Comparing the Model to an Ommatidium

Passaglia et al., 1998

How does Reichardt model compare to the Cell-Based Model?

- ?
- Discuss

What is a Transfer Function?

- A transfer function is the relation between the input and the output of a system
- In the case of the *Limulus*, the lateral eye is not equally sensitive to all spatial and temporal frequencies
- Rather, it is maximally sensitive to a particular range of spatiotemporal frequencies
Measuring Transfer Functions

- In order to understand the relationship between inputs and outputs...
  - Must manipulate the input (such that a known set of inputs is presented to the animal or the model) and measure the output
  - The relationship between input and output is what the term "transfer function" refers to
- Once this function has been plotted, the response to an arbitrary stimulus can also be determined
- Spatial input: drifting sinewave gratings of various frequencies
- Temporal input: modulating a spot of light

Why Look at Transfer Functions in the *Limulus*?

- Allows for the understanding of the spatial and temporal frequencies to which the *Limulus* is maximally sensitive
- This allows for an understanding of the optimal size, shape, speed, and other stimulus properties for a visual response
- Also sheds light onto the biological significance of the visual system’s responses

Results and Conclusions

Passaglia et al., 1997

Passaglia C et al. PNAS 1997;94:12649-12654

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Responses of Single Optic Nerve Fibers

Confirms the accuracy of the model

Passaglia et al. PNAS 1997;94:12649-12654

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Responses of Arrays of Optic Nerve Fibers

Each pixel=an ommatidium in the eye
Gray level=the optic nerve firing rate computed for that ommatidium at an instant in time
Rows 1 and 3 show small clusters of ommatidia responding with transient increase and decrease in firing rate in response to images of moving objects
Recall Lecture 16:
A light stimulus would induce a transient train of spikes followed by an adapted response.

Adapted from Hopkins, C.D., 2011

Q. How might neurons distinguish responses to moving crab-size objects from those evoked by other stimuli?

- Temporal integration
  - SNR (signal-to-noise ratio) of simulated responses of brain neurons to moving images of gray and black objects is maximum at ~400ms.
  - Integrating optic nerve responses over periods longer or shorter than 400ms yields less robust responses to the moving crab-size objects.

D: Simulated responses of brain neurons by the activities of an equal number of ommatidia located in a horizontal row of the model eye.

Seeing High Contrast and Low Contrast Objects

Visual image vs. Neural image

Passaglia et al., 1997
Conclusions

- The cell-based model accurately models the neural image produce by the ommatidia of the lateral eye
- The *Limulus* eye sends neural images to the brain that are highly sensitive to motion
- The *Limulus* lateral eye is also highly sensitive to objects of the same shape, size, and that move with the same velocity as a horseshoe crab

Citations

- [http://www.scholarpedia.org/article/Hartline-Ratliff_model#Hartline61](http://www.scholarpedia.org/article/Hartline-Ratliff_model#Hartline61)