Ideal Observer Analysis of Flash Detection in Blowfly Photoreceptor

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Introduction

• **Motivation:** Previous work established *information channel capacity* (maximum information rate) of the blowfly photoreceptor using a biophysical model of phototransduction. Here we investigate task specific information transmission in the same system using the tools of parametric estimation and detection. Our goal is to understand the relationship between task specific information and maximum information in a neural system.

• **Objective:** We analyze the performance of the blowfly photoreceptor model for the task of intensity flash detection using an ideal observer. We determine the flash intensity threshold (75% correct detection rate) as intensity varies.

• **Results:** We find that: a) detection threshold increases with background light according to a power function; b) threshold for low light levels is limited mainly by the photon noise and threshold at high light levels is limited mainly by the channel noise.

Fly's Eyes and Phototransduction
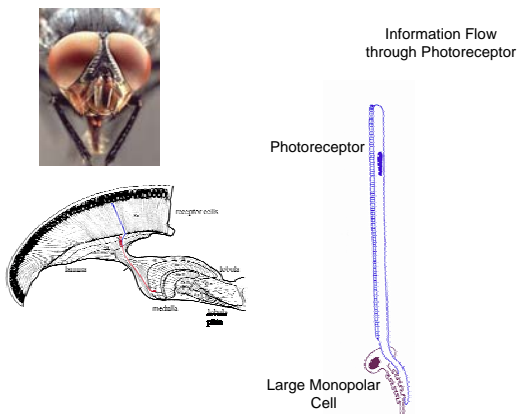
## Biophysical Phototransduction Model
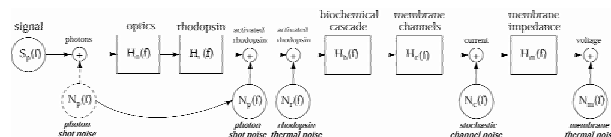
Photoreceptor transduction modeled as a communication channel by a cascade of linear signal transformations:

• Signal transformations: optics, rhodopsin, biochemical cascade, membrane channels, and membrane impedance.

• Noise sources: photon shot noise, rhodopsin thermal noise, stochastic channel noise, and thermal noise due to the membrane impedance.

Two main stages responsible for time course of response:

• Biochemical cascade modeled by a gamma function:

$$h(t) = \frac{h_b}{n_b! \, t_b} \left(\frac{t}{t_b} \right)^{n_b} e^{\frac{-t}{t_b}} u(t)$$
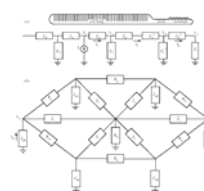

• Membrane impedance computed by a cable model of axon loaded by five other photoreceptors:

Ideal Observer Analysis

• 2-Alternative Forced Choice (2-AFC) flash detection task: one of two stimuli (flash or background) is presented in an interval, and the subject (ideal observer) is required to select one of the two choices (flash present, flash absent) based on its observations (membrane voltage at synaptic terminal) in the interval.

• Test statistic: $d^2 = (m_1 - m_0)^T K^{-1} (m_1 - m_0)$, where m_0, m_1 are mean observation vectors under the two stimuli, K is the covariance matrix.

• Detection error: $\Pr(error) = 1 - N(d/2)$, where N is the cumulative distribution function of a standard normal variable.

Assumption: Noise is normally distributed and equal for both stimuli.

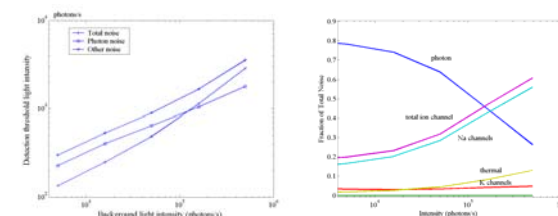## System responses to Flash Stimuli
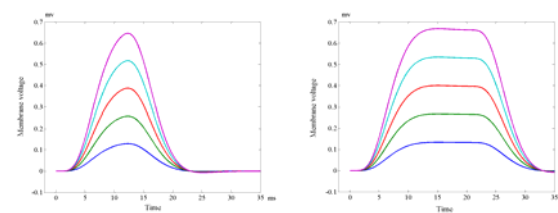
Stimulus duration: 20ms   Stimulus duration: 10ms

Flash stimuli intensities: 2-10% of the background (5000 photons/s) in increments of 2%. Stimulus starts at 0ms.

Performance of the Ideal Observer

Performance of the ideal observer under different background light intensities and different noise components.

Fraction of the total output noise at the synaptic terminal contributed by each independent noise source as a function of background light.

Summary

• We determine how performance of flash detection depends on background light and on different noise components.

• We provide a framework to investigate the relationship between task specific information and general information capacity.

Acknowledgement