A Model Lateral Geniculate Complex

Noise Suppression and Input Trajectory Discernment in the Turtle Visual System

Ronald C. Anderson

Center for Bio-Cybernetics and Intelligent Systems
Department of Mathematics and Statistics
Texas Tech University
Lubbock, TX, 79409, USA

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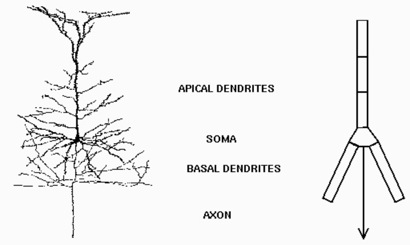
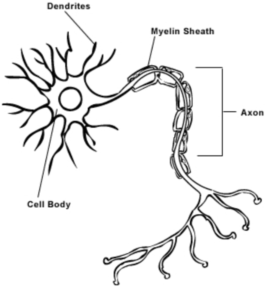
Some Preliminaries



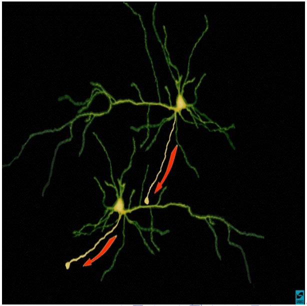
What is a neuron?

- Special purpose cell in the nervous system
- Link together (via synapses) into networks
- Send electro-chemical signals to each other
- Weighs received signals and conditionally messages others

General Neuron Structure

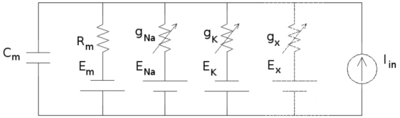


Two-Neuron Network



Basics of the Hodgkin-Huxley Model

Cell Exterior



Cell Interior

Via current analysis and the law of energy conservation:

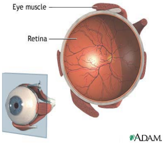
$$-C\frac{dV(t)}{dt} = I_{Na^+}(V,t) + I_{K^+}(V,t) + I_m(t) - I_{in}(t)$$

This equation underlies the Hodgkin-Huxley Neuron model (HH).

The GEneral NEural SImulation System (GENESIS) uses this equation to model neuron behavior.

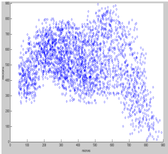
The Turtle Visual System

The turtle visual system consists of many interacting neural systems. Three components of note:



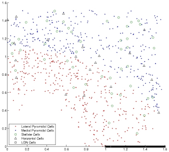
The Retina

Contains neurons responsible for perceiving light and converting it to neural signals



Lateral Geniculate Complex

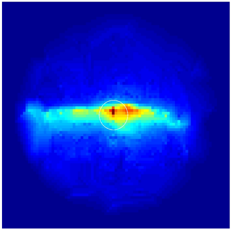
Intermediate structure in the brain that receives retinal input and processes/transmits it to the visual cortex

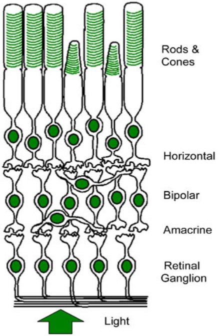


The Visual Cortex (VC)

Region of the brain containing neurons involved with visual processing

Modeling the Biological Facts





The Freshwater Turtle Retina

- The density of ganglion neurons varies across the retina
- The highest density exists along a 'visual streak'

The GENESIS Model [1, 2, 4]

- Extant prior to this thesis project
- Model consists of 520 ganglion neurons
- Cells reside in the white circle 'patch' to the left
- Both direction sensitive and insensitive ganglion included

Modeling the Biological Facts

The Freshwater Turtle Visual Cortex

- Consists of neurons of many morphologies
- Vital for processing input from LGC/Retina

The GENESIS Model [1, 2, 3]

- Extant prior to this thesis project
- Model consists of 744 neurons
- Four neuron classes included: horizontal, stellate, medial, and lateral

What is the study motivation?

General question:

How do the retina, LGC, and visual cortex interact to process visual input?

Thesis conjecture:

The LGC may assist in rejecting retinal noise.

Research project goals:

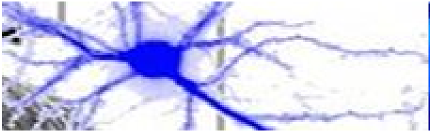
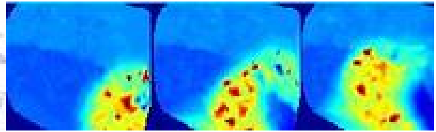
- Construct an LGC model
- Fuse LGC to VC and retina
- Inhibit noise from retina
- Conduct angle input tests

Study results include:

- Conjecture is supported
- Angle discernment shows promise

Construct the LGC Model

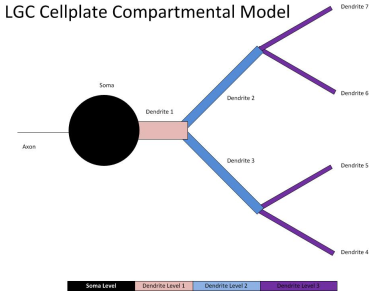
Construct the FVSM
Inhibit Retinal Noise
Conduct Angle Input Tests

Sub-cellular Models

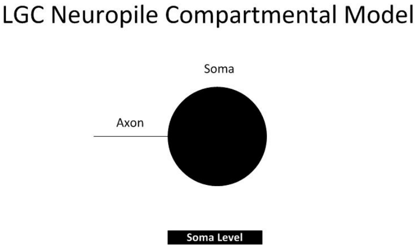
Cell plate Model:

- Soma is a spherical compartment
- Each rectangle is a cylindrical compartment



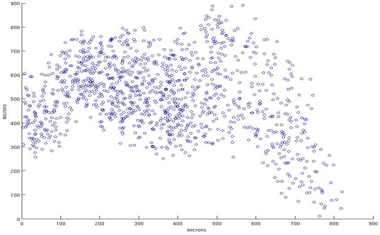
Neuropile Model:

- Soma is a spherical compartment
- No dendrites are modeled (basic model only)

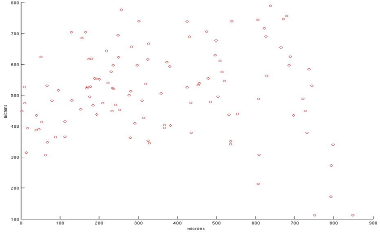


Modeling the Biological Facts

Cell Plate Neuron Distribution



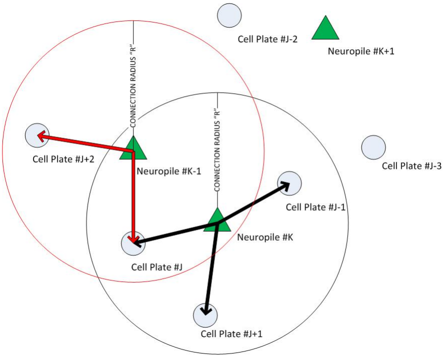
Neuropile Neuron Distribution



The GENESIS Model[1, 5]

- 1,169 cell plate neurons
- 112 neuropile neurons
- Model Cells distributed according to biological data
- In model, neuropile cells can inhibit cell plate activity

Connecting Neuropiles to Cell Plates



The neuropile layer will inhibit noise from the retina.

Connection procedure:

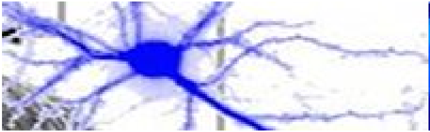
- Select Neuropile cell
- Center circle about cell
- Find cell plate cells within radius
- Create inhibitory synaptic connection from neuropile to cell plate
- Repeat for all Neuropiles

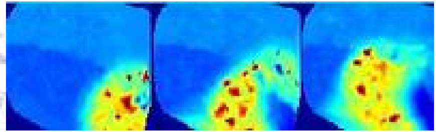
Construct the LGC Model

Construct the FVSM

Inhibit Retinal Noise

Conduct Angle Input Tests



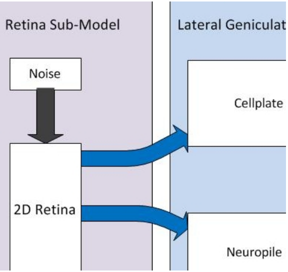


Engineering the Turtle Visual System

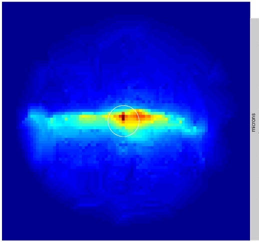
We constructed a GENESIS model of the freshwater turtle visual system:

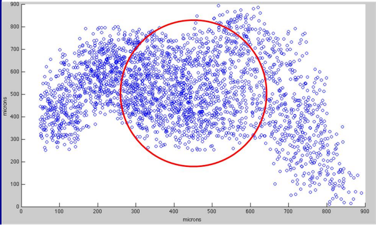
- Retina [2]
- Lateral Geniculate Complex [1]
- Visual Cortex [5]

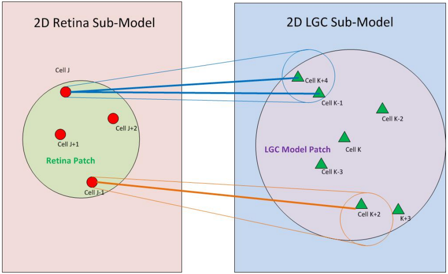
Such a model promises new understanding of visual processing in the brain.



The Retina/LGC Interface



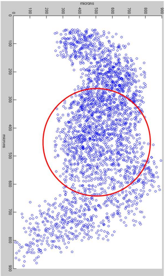


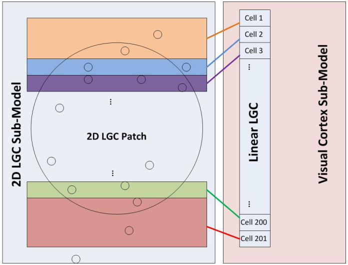


Connection procedure:

- Map each retina cell in patch to LGC patch
- Define radius about retina cell
- Find cell plates in radius
- Create synaptic connections

The LGC/VC Interface

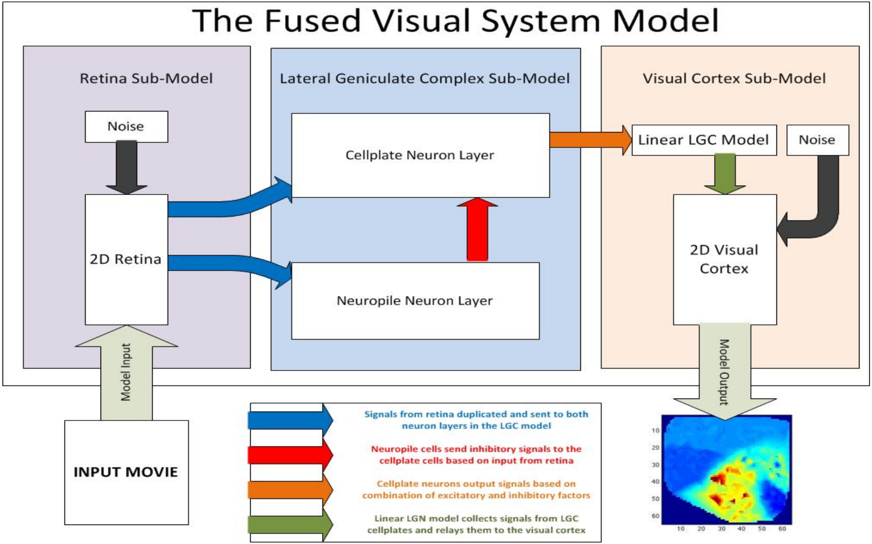




Connection procedure

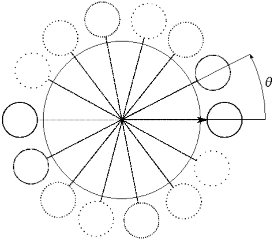
- Define 201 vertical rectangular strips to sub-divide LGC patch
- Extract X coordinate of each LGC cell plate neuron
- Classify each neuron into the 201 strips
- Synaptically connect cells in strip K to Linear LGN cell K

The Complete FVSM

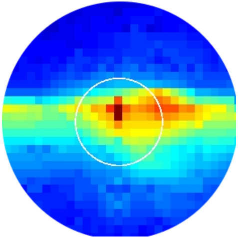


Retina Movie Input

a) Retina Movie Input



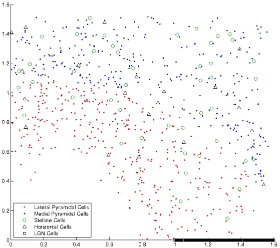
b) Model Retina Patch

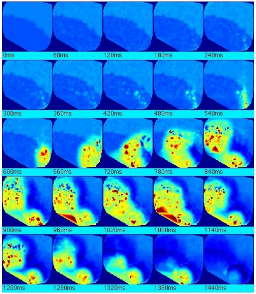


Before discussing results, we define input to the FVSM:

- Large circle in a) is the white circle in figure b)
- Small circles in a) represent simulated point light sources
- Each movie includes one point source incident to retina at angle $n\theta$, where $n \in [1, 2, ..., 12]$
- We define $\theta = 30^\circ$ in this study
- Retina noise is added to each cell in the patch independent of movie

FVSM Output Data





Visual Cortex Model

- ○ represents Stellate neurons
- △ represents Horizontal neurons
- Blue dots are Medial neurons
- Red dots are Lateral neurons

Time-slice of Cortex Activity

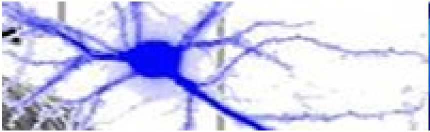
- Blues represent low activity
- Yellows represent intermediate activity
- Orange and red represent high activity
- The 'wave' produced is called the 'cortical wave'

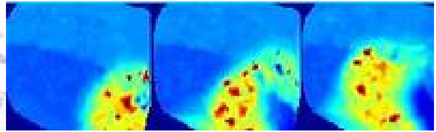
Construct the LGC Model

Construct the FVSM

Inhibit Retinal Noise

Conduct Angle Input Tests



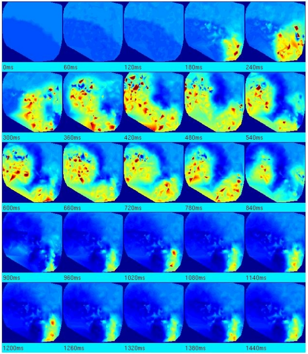


Retina Noise: Supression vs. No Supression

Here, we look at the cortex response to noise in the retina (no movie used). Note how activating inhibition stops retinal noise from triggering a cortical wave.

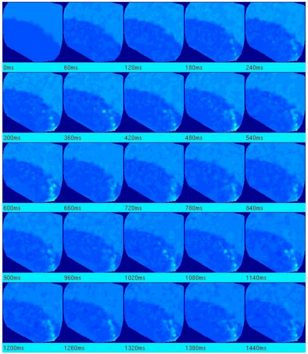
Cortex response:

with noise, no inhibition



Cortex response:

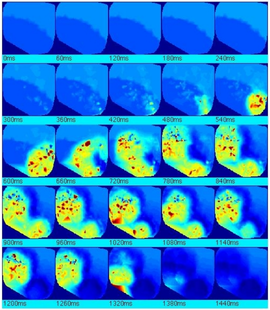
with noise, with inhibition



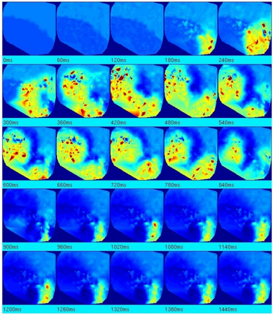
Retina Noise Suppression Results

Here, we look at the results of noise suppression with input angle 150°. Other angle inputs are similar.

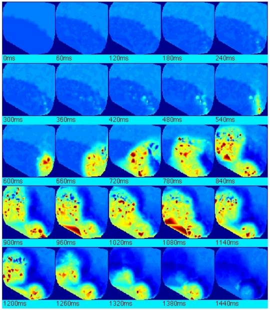
Cortex response:
no noise, no inhibition



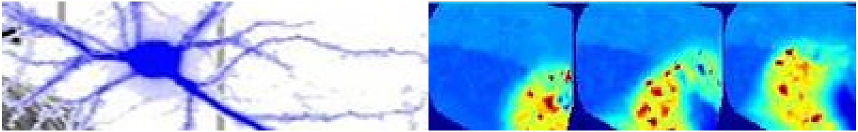
Cortex response:
with noise, no inhibition



Cortex response:
with noise, with inhibition



Conduct Angle Input Tests



Angular Input Cortical Responses

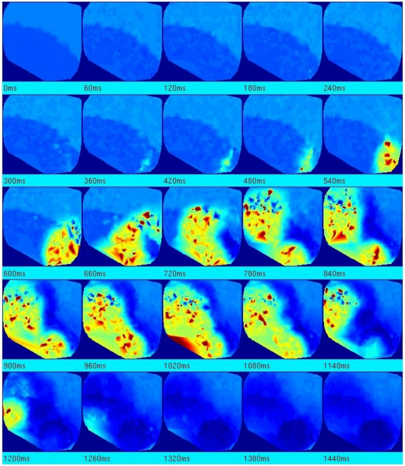
The next six slides display the cortical waves from the FVSM to the given angular input.

NOTES:

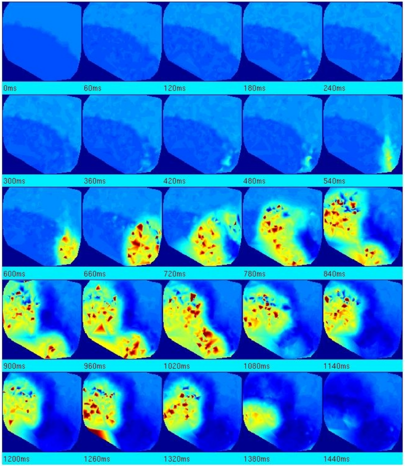
- Noise and inhibition are active in all cases
- All model parameters identical in each case.
- The noise levels used are:
    - Cortex: $variance = 4x10^{-10}$
    - Retina: $variance = 1x10^{-9}$

Angular Input Cortical Responses

Input angle 0°:

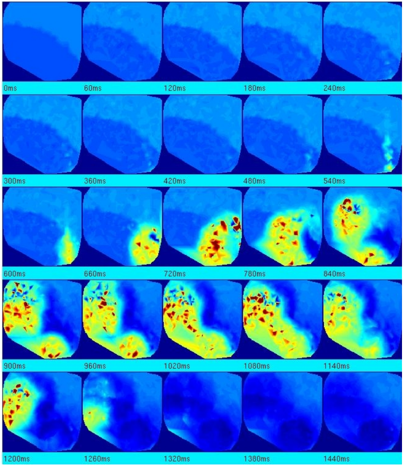


Input angle 30°:

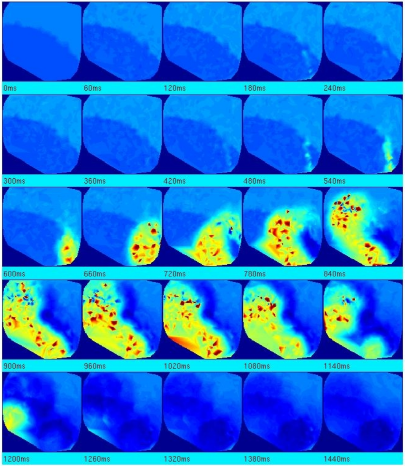


Angular Input Cortical Responses

Input angle 60°:

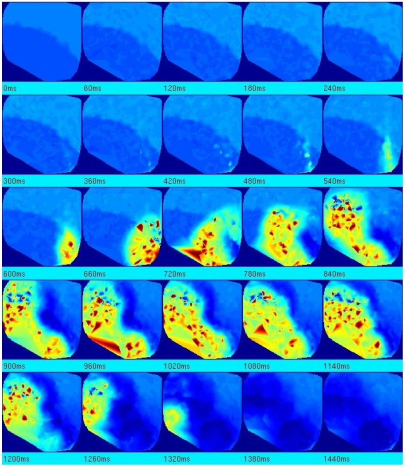


Input angle 90°:

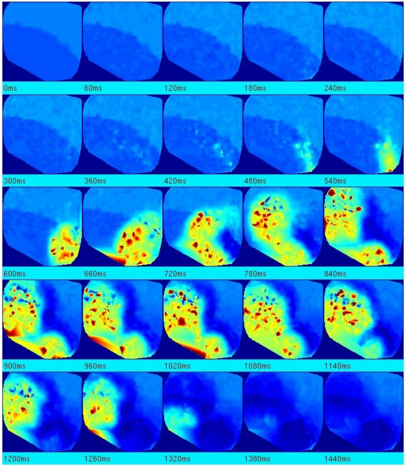


Angular Input Cortical Responses

Input angle 120°:

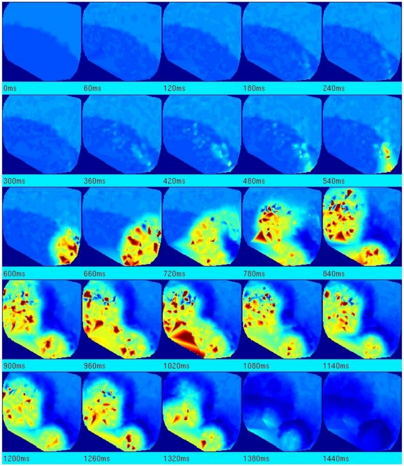


Input angle 150°:

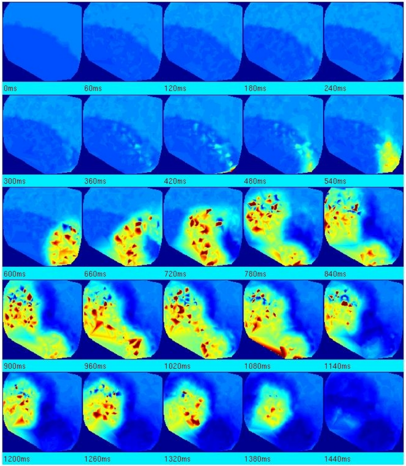


Angular Input Cortical Responses

Input angle 180°:

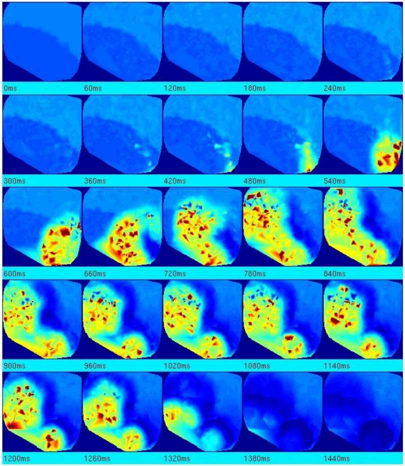


Input angle 210°:

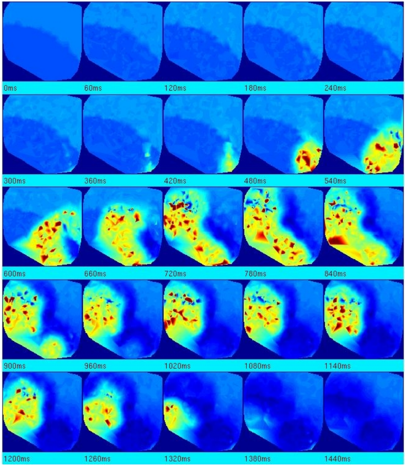


Angular Input Cortical Responses

Input angle 240°:

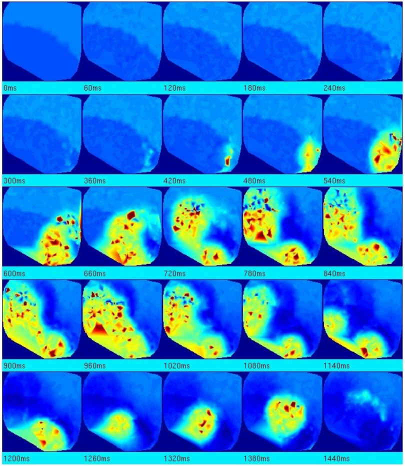


Input angle 270°:

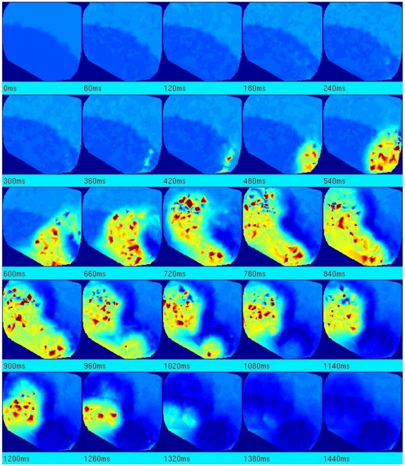


Angular Input Cortical Responses

Input angle 300°:

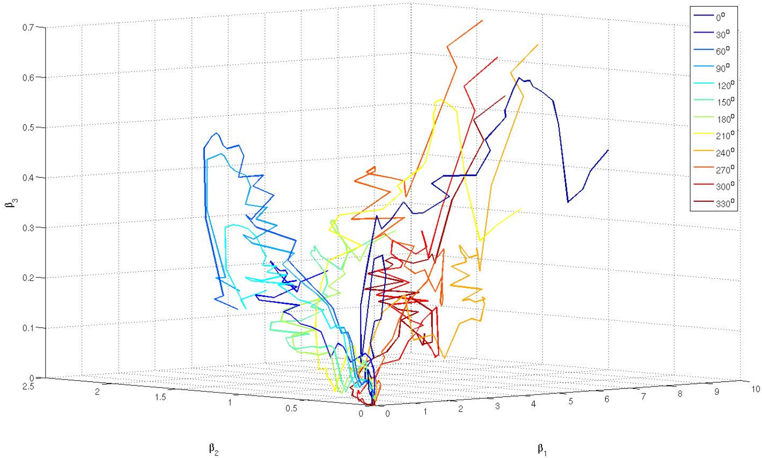


Input angle 330°:



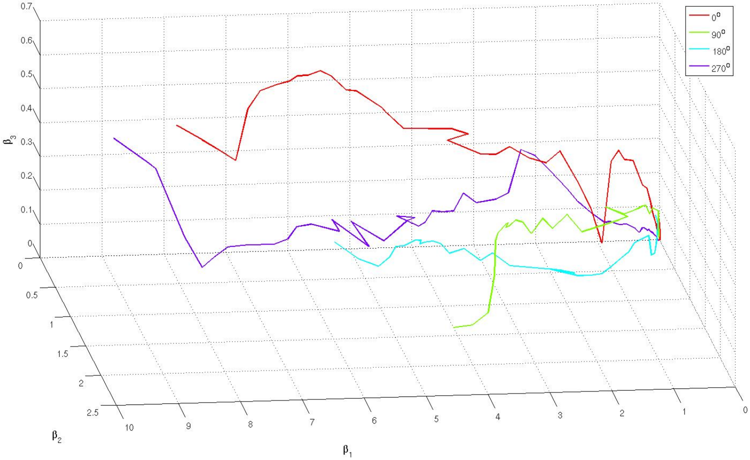
Angle Discernment with KL PCA

All angles: 0ms - 800ms



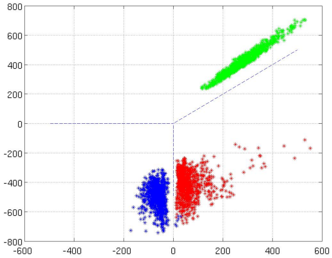
Angle Discernment with KL PCA

Cardinal angles: 0ms - 800ms

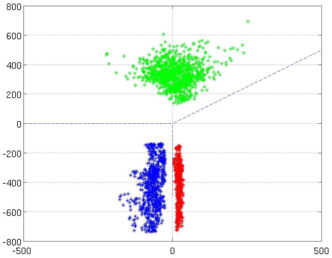


Decision Space Samples

450ms: 240°, 270°, 300°

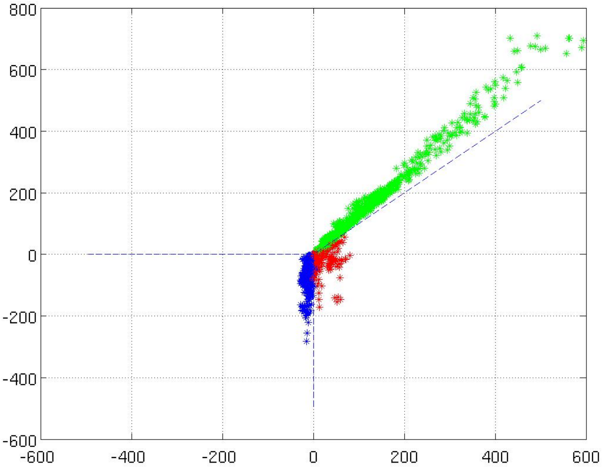


450ms: 300°, 330°, 0°



Decision Space Samples

450ms: 150°, 180°, 210°



Where do we go from here?

This work contributes to our understanding of the turtle visual system. However, more can be done.

- Modify model parameters to improve separation results
- Tweak parameters to allow greater noise variance ranges in the retina
- Expand FVSM to utilize the full LGC
- Apply more complex mappings from retina to LGC

Acknowledgments

Thesis Committee

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- Dr. Clyde Martin

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- Dr. Philip S. Ulinski

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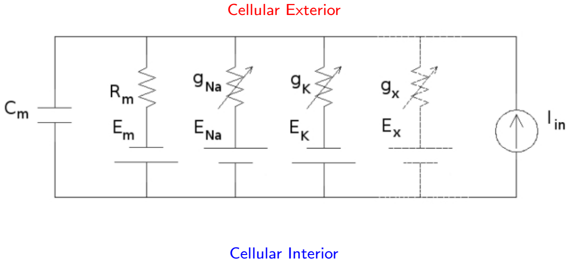
Basics of the Hodgkin-Huxley Model

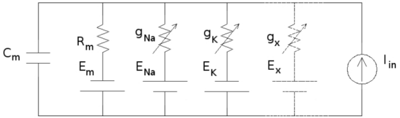
The Hodgkin-Huxley model can be represented in circuit diagram form as:



HH Circuit diagram: Arrows through each resistance represent conductances that can vary with respect to the applied voltage.

E_x represents arbitrary ionic channels besides those of Na or K.

Basics of the Hodgkin-Huxley Model



Via current analysis and the law of energy conservation:

$I_{in}(t) = I_C(t) + I_m(t) + \sum I_x(t) = I_C(t) + I_{Na^+}(t) + I_{K^+}(t) + I_m(t)$
Then, $-I_C(t) = I_{Na^+}(t) + I_{K^+}(t) + I_m(t) - I_{in}(t)$

Recall: $I(t) = C\frac{dV(t)}{dt}$ Thus,

$$-C\frac{dV(t)}{dt} = I_{Na^+}(t) + I_{K^+}(t) + I_m(t) - I_{in}(t)$$

This equation underlies the Hodgkin-Huxley Neuron model, hereafter HH.

Basics of the Hodgkin-Huxley Model

The ionic channels are gated (represented by the variable resistances in the circuit model). These 'gates' are voltage-dependent. So for emphasis we write:

$$-C\frac{dV(t)}{dt} = I_{Na^+}(V,t) + I_{K^+}(V,t) + I_m(t) - I_{in}(t)$$

The HH Neuron Model is implemented in the GEneral NEural SImulation System (GENESIS), and we develop all of our models using this system. Part of the model development process is providing the cellular parameters to fit this equation to specific neuronal behavior.

Basics of the Hodgkin-Huxley Model

Below is a typical action potential, or 'spike'. These spikes are the messages for neuronal communication.