Target Motion Discrimination with Model Retina and Cortex

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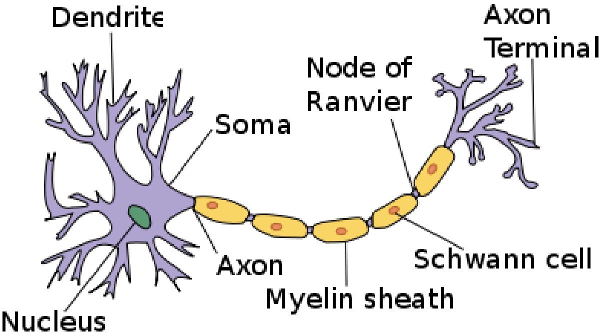
- The combined model of the visual system of a freshwater turtle is studied to discriminate motion targets.
- This presentation consist of the following:
  - The Biological Model of the Turtle Visual System
  - Simulation Model of the Turtle Visual System
    - Effects of Simulation Parameters
  - Simulation Results
  - Target Discrimination using Simulation Results

Turtle Visual System

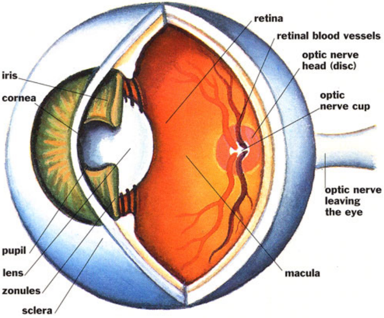
- Freshwater Turtle Visual System is a simple yet complete Vertebrate visual system
- It Consist of Retina, Lateral Geneculate Complex (LGN) and Visual Cortex

Neurons

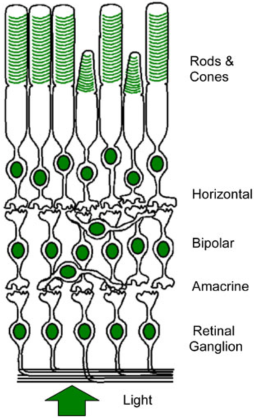


- Neurons are special purpose cells and are the building block of the visual system
- Neurons are connected to each other through synaptic connections

The Retina



The retinal is a part of the eye on which the image is formed.

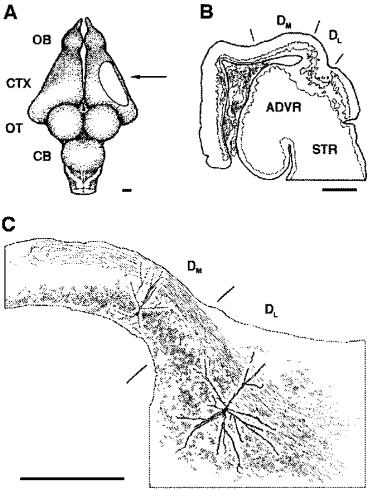


The Retina

The retina consist of

- Rods and Cone Cells - Color Sensitive - Acts as a filtering layer
- Ganglion Cells
    - Direction Insensitive Cells (A-ON, A-OFF cells)
    - Direction Sensitive Cells (B1, B2 and B3 Cells)
- We only model Ganglion cells in our model

Visual Cortex



A: Dorsal view of a turtle brain. The oval-shaped area represents the visual cortex, which corresponds to the dorsal area, D. OB, olfactory bulb; CTX, cortex; OT, optic tectum; CB, cerebellum.
B: Coronal section through the cerebral cortex at the level indicated in A. ADVR, anterior dorsal ventricular ridge; STR, striatum; D_M, medial part of D; D_L, lateral part of D.

C: Detailed view of visual cortex showing a medial and lateral pyramidal cell

Visual Cortex (Contd...)

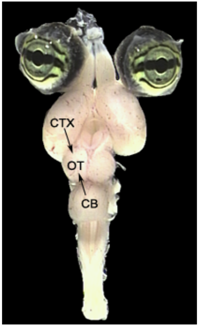


Figure: Turtle eyes and the Dorsal view of its brain CTX, cortex; OT, optic tectum; CB, cerebellum

The Visual Cortex model consist of

- Lateral Pyramidal Cells
- Medial Pyramidal Cells
- Stellate Cells
- Horizontal Cells

Visual Cortex (Contd...)

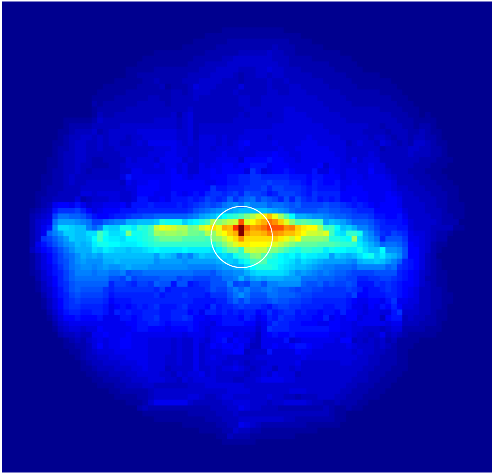
Neuronal activities in the turtle's visual system have been studied using different methods

- Recording from external surface of the brain using multi-electrode arrays (Prechtl, 1994; Prechtl et al.,2000)
- Imaging the external surface of the cortex with voltage-sensitive dyes (Prechtl et al., 1997)
- Imaging the ependymal surface of the cortex with voltage-sensitive dyes (Senseman, 1996, 1999; Senseman and Robbins, 1999, 2002)

Turtle Visual System - Simulation Model

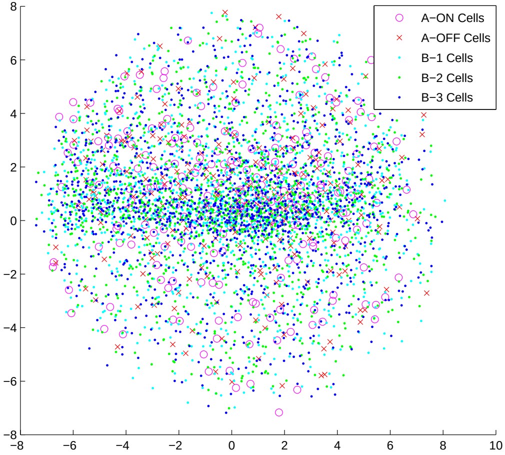
- Simulation models for Turtle Retina and Visual Cortex was developed at Center for Bio Cybernetics & Intelligent Systems and other collaborated institutes.
- The model uses GENESIS neural simulator and Hodgkin-Huxley Model to simulate neurons.

The Retina Cell Distribution



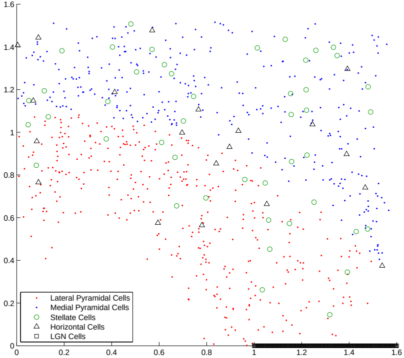
- This figure shows the cell distribution of the entire retina.
- We model a patch of 520 cells from the center of the retina which is indicated by a white circle.

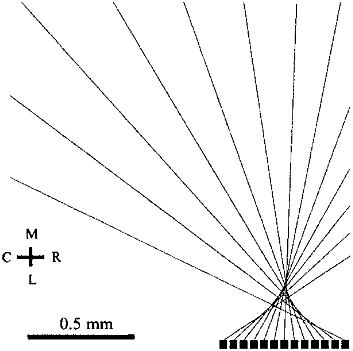
The Retina Model



The Visual Cortex Model

The visual cortex model consist of 744 neurons is shown below.





A Linear LGN is also indicated here as a black stripe

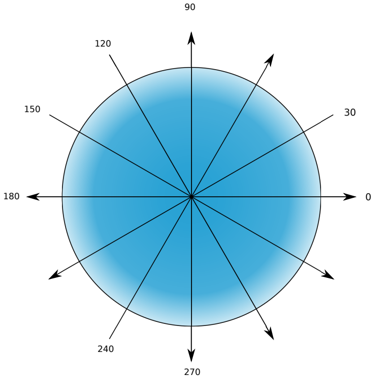
Synaptic Connections in Visual Cortex

Connection Between Retina and Visual Cortex

- A Linear LGN with 201 cells is modeled
- Ganglion cells from retina is connected linearly to LGN based on their x-coordinate.
- Delayed Synaptic connections were made based on the y-coordinate of Ganglion cells of the retina

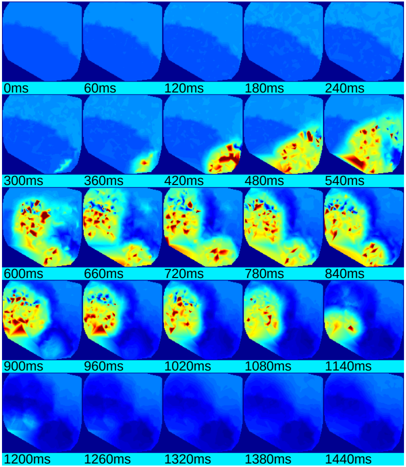
Simulation Study

- A simulated input data for eight different motion paths were used in this simulation
- The Visual cortex cell activity levels (Cortical responses) were recorded over time and activity movies are generated.
- 1.5s of Turtle's Visual Cortex activities were simulated.

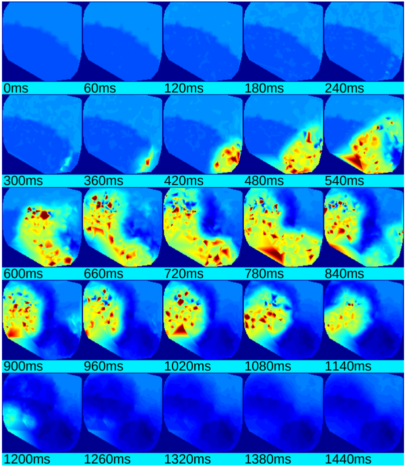


Motion Paths corresponds to $0^\circ, 30^\circ, 90^\circ, 120^\circ, 150^\circ, 180^\circ, 240^\circ, 270^\circ$

Visual Cortex Activity Movies

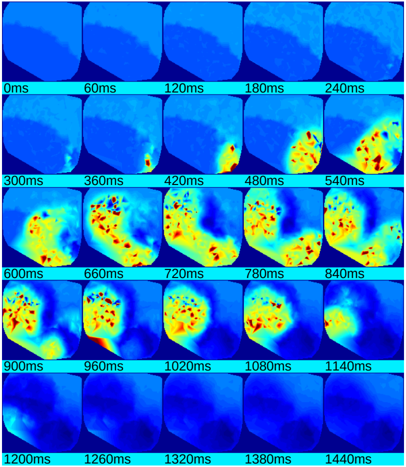


Movie frames for motion path corresponds to 0°

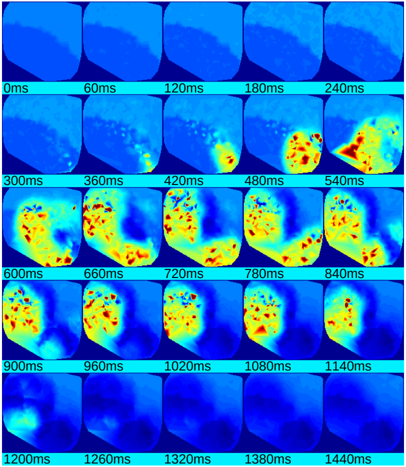


Movie frames for motion path corresponds to 30°

Visual Cortex Activity Movies

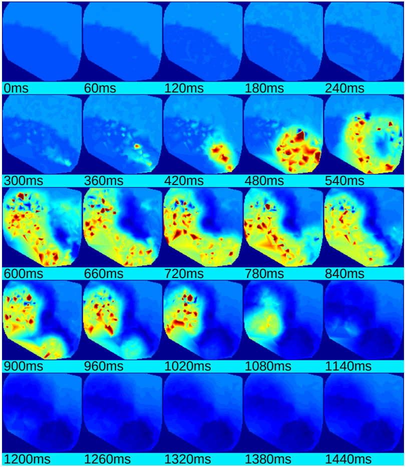


Movie frames for motion path corresponds to 90°

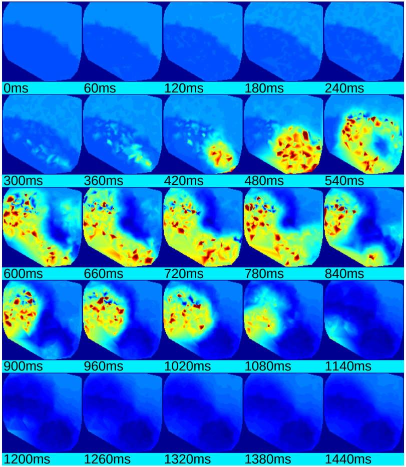


Movie frames for motion path corresponds to 120°

Visual Cortex Activity Movies

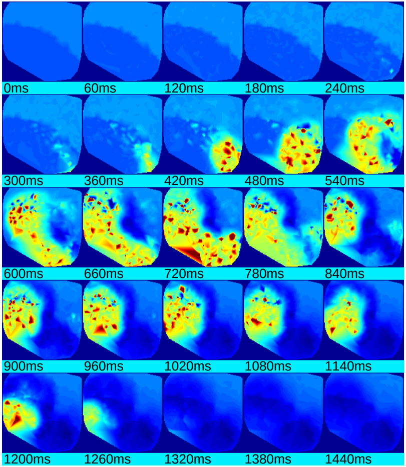


Movie frames for motion path corresponds to 150°

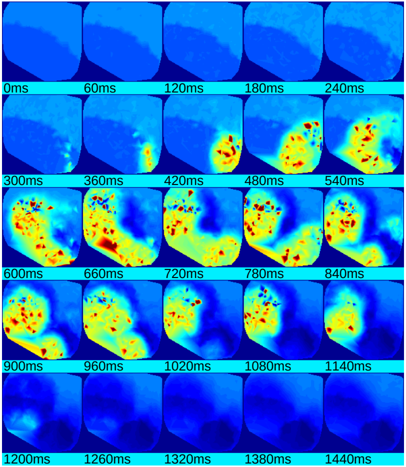


Movie frames for motion path corresponds to 180°

Visual Cortex Activity Movies

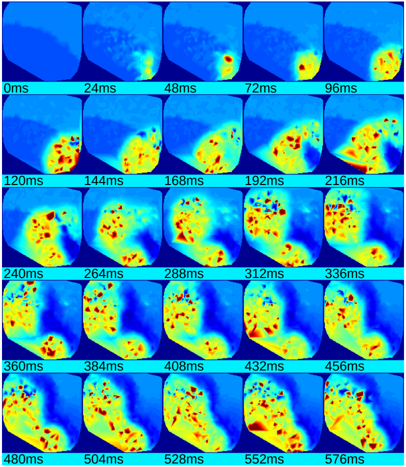


Movie frames for motion path corresponds to 240°

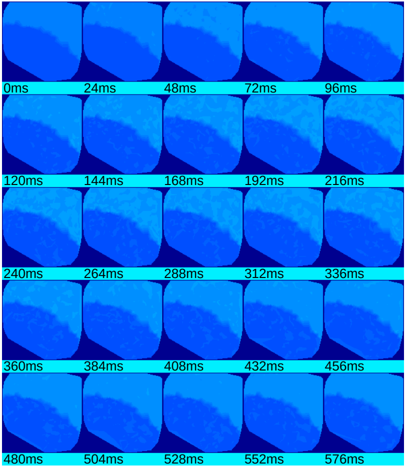


Movie frames for motion path corresponds to 270°

Dynamic Connection weight Adjustment

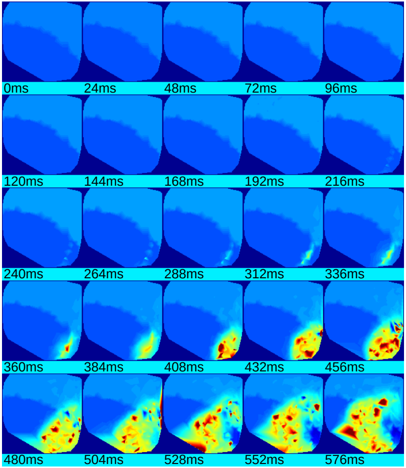


If Connection Weights are not adjusted dynamically with no input signal

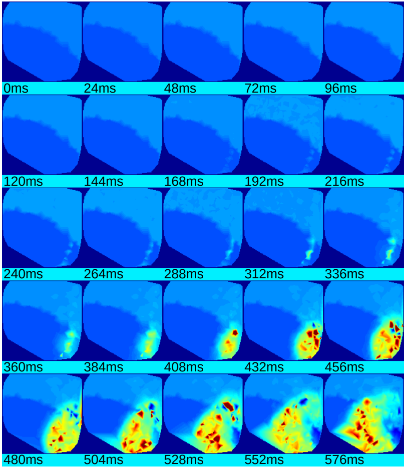


If Connection Weights are adjusted dynamically with no input signal

Visual Cortex White Noise

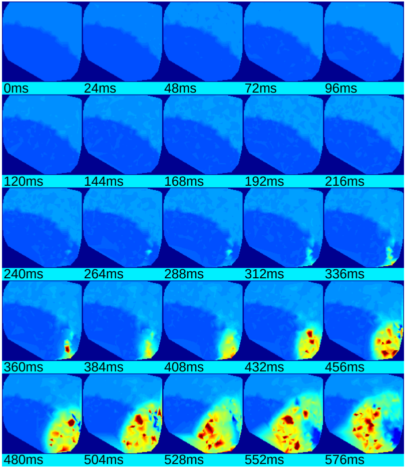


With white noise level 3.0×10^{-12}

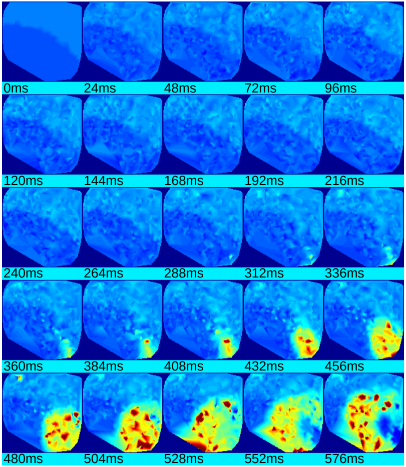


With white noise level 3.0×10^{-11}

Visual Cortex White Noise



With white noise level 3.0×10^{-10}

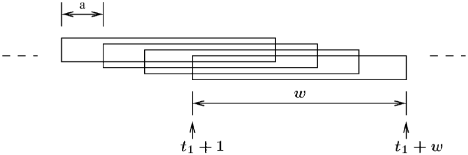


With white noise level 3.0×10^{-9}

Principal Component Analysis

- The cortical response waves can be seen as movies with a frame sequence, each of which represent the level of depolarization at an array of points in the cortex
- A Two step Karhunen-Loeve (KL) Decomposition is used to decode the information encoded in these waves (Nenadic et. al, 2002; Du, Ghosh, Ulinski, 2005) with Sliding Encoding Window method.
- Results of each decomposition are known as α components and β components respectively.
- A Gaussian white noise level of 3.0×10^{-10} is introduced to the Visual Cortex model during the simulation.

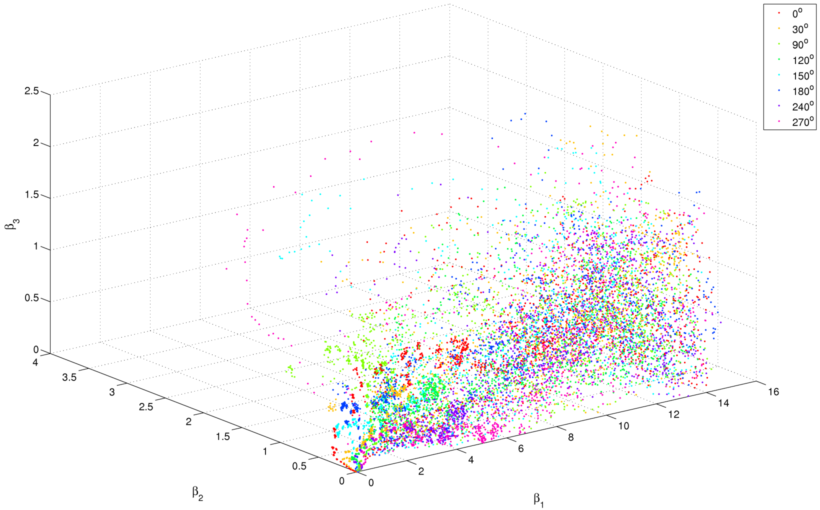
Slide Encoding Window Method



Encoding window: The time axis is covered by equal-length, overlapping sliding encoding windows.

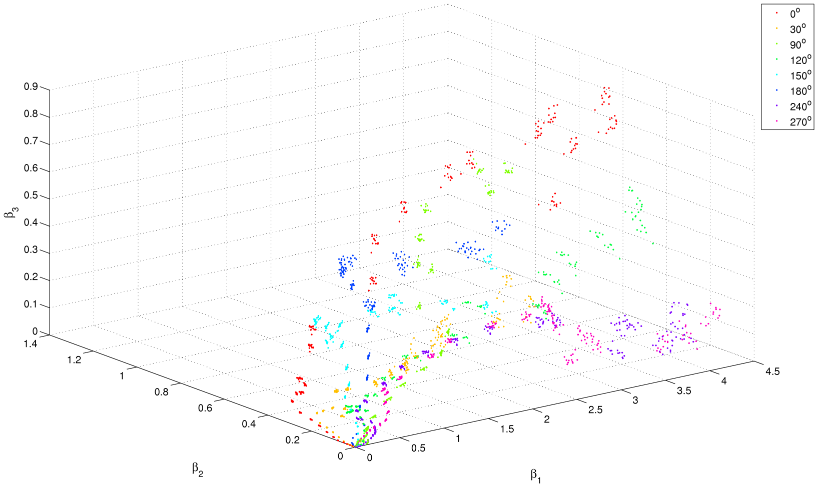
- a is the amount of time that the window slides
- w is the width of each encoding window. "
- In this simulation, a sliding window of $a = 10ms$ and $w = 100ms$ is used.

β Components



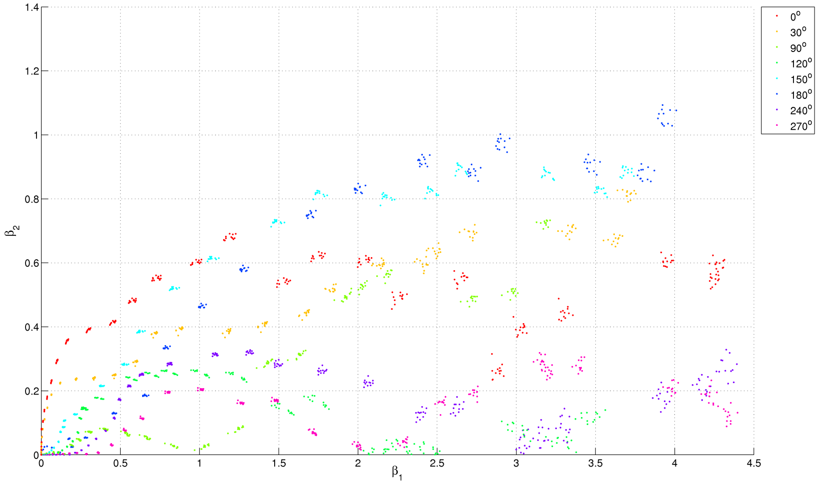
Plot of three leading β components β_1, β_2 and β_3 for time t=0ms to t=1400ms between all motion paths

β Components



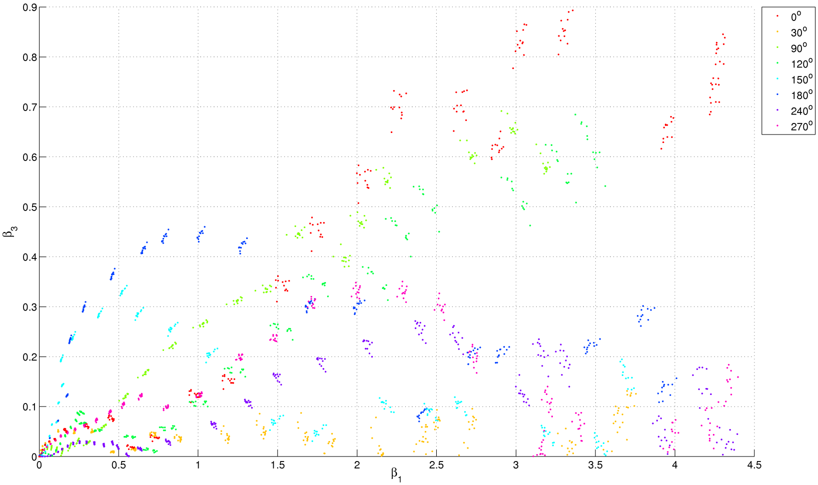
Plot of three leading β components β_1, β_2 and β_3 for time t=0ms to t=500ms between all motion paths

β Components



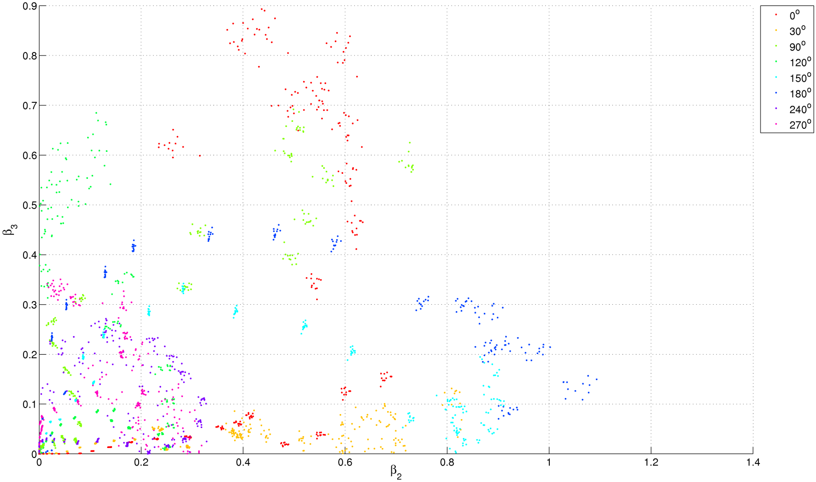
Plot of two leading β components β_1 and β_2 for time t=0ms to t=500ms between all motion paths

β Components



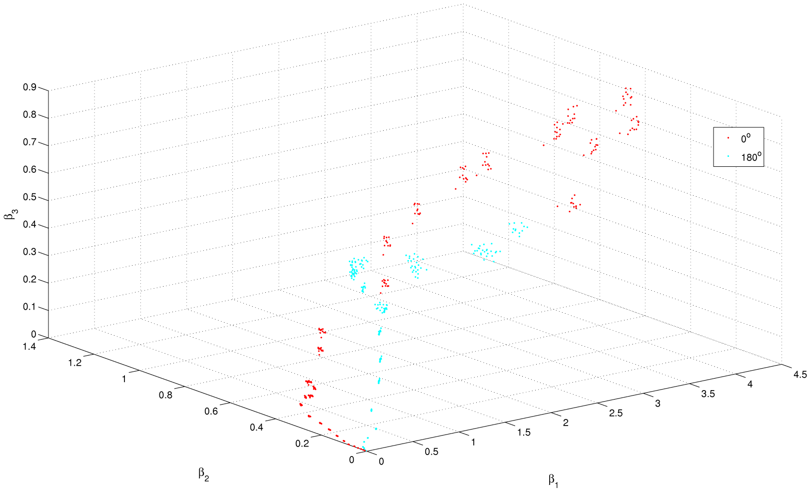
Plot of two leading β components β_1 and β_3 for time t=0ms to t=500ms between all motion paths

β Components



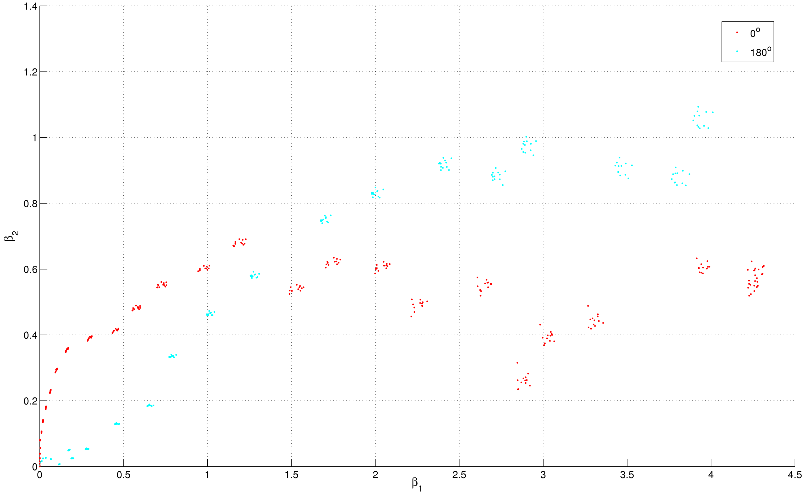
Plot of two leading β components β_2 and β_3 for time t=0ms to t=500ms between all motion paths

β Components



Plot of three leading β components β_2 and β_3 for time t=0ms to t=500ms between two motion paths

β Components



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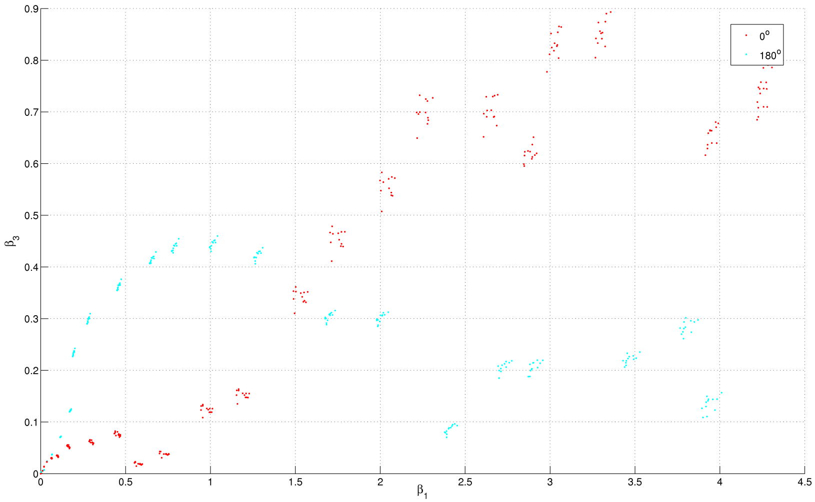

Plot of three leading β components β_2 and β_3 for time t=0ms to t=500ms between two motion paths

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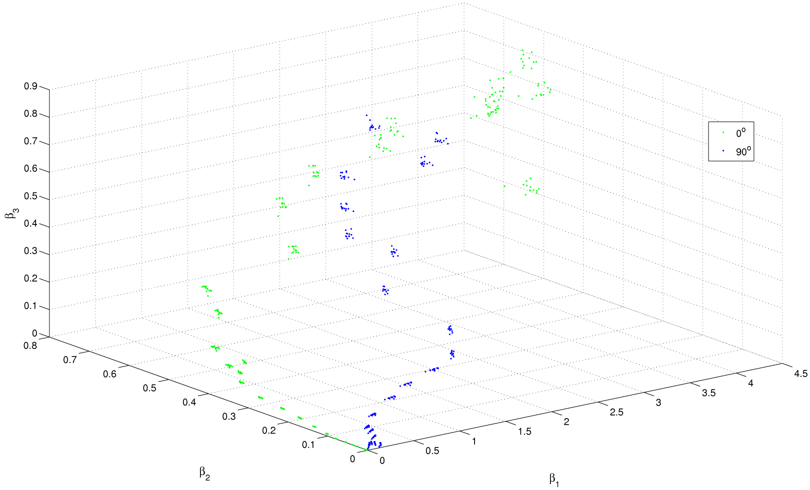
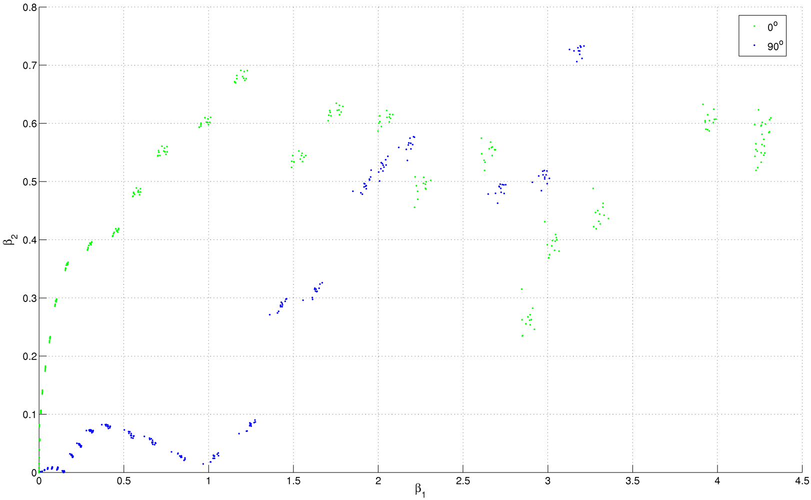


Plot of three leading β components β_2 and β_3 for time t=0ms to t=500ms between two motion paths

β Components



Plot of three leading β components β_2 and β_3 for time t=0ms to t=500ms between two motion paths

Conclusion

- It can be clearly see that the combined model Retina and Visual Cortex discriminates motion targets with different directions of motion.
- The best detection window is 0ms - 500ms with the present simulated parameters.
- Adaptive synaptic weights should be used to avoid interfering waves from retina

Thank You!

I would like to express my sincere thank to

- Dr. Bijoy K. Ghosh, my thesis advisor
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- My Wife Kalpana
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